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THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

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Articles PAGE

Telescope Mountings for Amateur Builders (With Plates XXV, XXVI) ..... *H. Boyd Brydon* 377
Evolution of the Solar System ..... From *Nature* 392
The Physical State of the Upper Atmosphere. (Continued from page 366) ..... *B. Haurwitz* 397

Meteor News
Observation of the Orionids in 1936 ..... *P.M.M.* 416

Notes and Queries
Civil War and Scientific Research—Recollections of Simon Newcomb—Optical Catalogues ..... *C.A.C.* 419

Meetings of the Society
At Vancouver—At Victoria 423

Index to Volume XXX, 1936 425

Title Page and Table of Contents

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Fig. 3.—Yoke type of Mounting as developed by Dr. H. Paige Bailey.

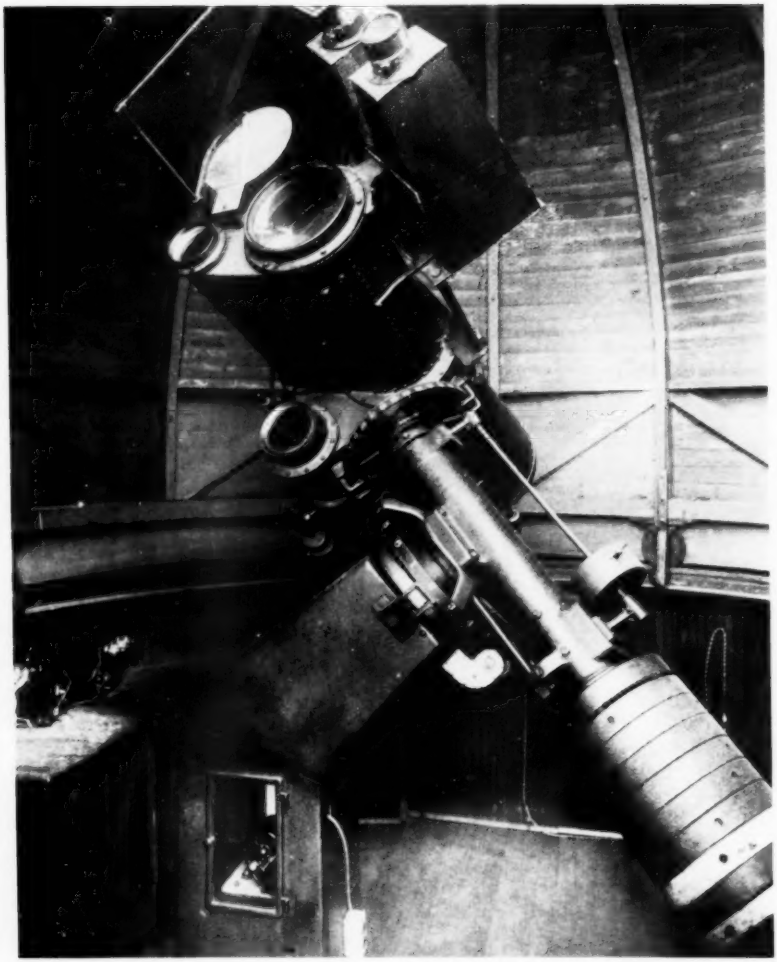

Fig. 4.—The Bruce Telescope of the Yerkes Observatory, showing the mechanism for driving the instrument and the Ross photographic and photovisual lenses attached.

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TELESCOPE MOUNTINGS FOR AMATEUR BUILDERS

By H. BOYD BRYDON

(With Plates XXV, XXVI)

I

THE amateur telescope builder to-day has available very complete information on the preparation of the optical parts of his telescope. With mountings, however, the situation is not as satisfactory.

It is true that the ability of the observer is more important than the quality of his instrument and that Bessel was correct if he said a good observer with a gun-barrel mounted on a cart-wheel will do better work than a bad observer armed with the best equipment; but it is at least equally true that the good observer could do vastly better work if given the good equipment. A good optical train is vital but there is little if any exaggeration in Dr. Louis Bell's remark that "a steady and convenient mounting is just as necessary to the successful use of the telescope as is a good objective".[1] Sir David Gill says practically the same thing,—"The proper mounting of a telescope is hardly of less importance than its optical perfection".[2] Unfortunately the amateur mounting is frequently neither steady nor convenient. "The ordinary amateur is inclined to mount his telescope in a very simple and inexpensive style. There is no doubt that a great deal of pleasure and profit may be obtained with even a crude mounting, but labour spent on mounting will be amply repaid in the pleasure of using the telescope, more especially if the telescope is to be used in useful research work"[3]

[1]Bell, The Telescope, Chap. V.

[2]Enc. Brit., Art. Telescope.

[3]R. K. Young, "The Building of a 19-in. Reflecting Telescope". This JOURNAL, vol. 29, p. 17, 1930. This important article was reprinted in *English Mechanics*, vol. 8, p. 475 *ff.*, 1930.

The reason for this condition is not far to seek. Very little definite information of reliable value is readily available on mountings. The mounting is generally dismissed with a statement to the effect that its design and construction may be safely left to the ingenuity of the mirror maker, and many of the pictures published seem to be selected less as examples of good design than to illustrate evolution from cart wheels to automobile axles.[4]

Such representations give a false idea of the difficulties that must be overcome in the design and construction of a good mounting. It is not an easy matter. On the contrary, as an experienced designer has well remarked "Few people who have not been through the mill will realize the difficulties and uncertainties attending the design of any new machine or applicance. If the machine be really a novel one and not merely an improved model of some perfectly well known appliance, these difficulties are immense and have to be experienced practically to be appreciated"[5] which is most true. When to this is added the difficulty of translating the design accurately into the actual mounting, the job is far from a simple one. For the amateur is severely handicapped. He is inexperienced in the thing to be produced. He is without much desirable and even necessary tool equipment and he is seldom a master in the use of the tools he does have. It is not remarkable that so tricky an apparatus as a good equatorial mounting is not readily produced by the amateur. Job for job, the mounting is by far the most difficult part of the work of building a telescope, as it is the most expensive. Dr. Young, for example, in the article quoted shows a cost for the tube and mounting of over three times the cost of the optical parts. Nonetheless, a well figured mirror is a beautiful thing and should be given as good a mounting as is possible.

In the building of a telescope mounting castings and machine work are the chief expense. Of course some machine work is unavoidable but much of this can be done by the builder himself, at a night technical school for instance, where good machine tools are

[4]The 4th Edition of *Amateur Telescope Making*, however, contains a useful discussion on the "Fundamentals in the design of Telescope Mountings" by R. W. Porter.

[5]*B.C.J., Eng. Mech.*, vol. 19, p. 268, Jan. 3, 1936.

available and the immensely valuable advice and help of the instructor is to be had for the asking; while by giving consideration in the design to the handicaps above mentioned, the number of castings and the expense of machining can be greatly reduced with little loss in effectiveness. In fact—

> Patience, care and perseverance will make up for lack of pelf
> What you can't afford to purchase you can always make yourself

and even the inexperienced amateur can achieve a steady and convenient mounting for a small part of the cost of a similar mounting professionally made.

Many items contribute to this lower cost. The amateur is doing the job as a hobby, for the joy of doing it, he does not need to consider labour cost. Then his telescope does not often exceed twelve inches in aperture and many little devices can be safely used that would be out of the question in larger instruments. Again the amateur may make use of approximations and simplifications that would be unacceptable in a professional mounting.

The professional worm wheel, for example, is laid out with the utmost care with the aid of micrometers and microscopes, with a definite number of teeth milled to the best shape to an accuracy of closer than one thousandth of an inch and then carefully ground until it is practically perfect. If he uses a worm drive, which is not essential, the amateur places a standard tap of suitable size and number of threads between his lathe centres, mounts the wheel blank on the cross-slide so as to be free to turn on its axis, brings it up against the tap, starts his lathe and the thread is cut on the wheel as the tap rotates. The precise number of teeth on the finished wheel does not matter as the speed of the clock or motor can be easily adjusted through a sufficient range to suit.

Again, hour and declination circles are most carefully turned to an exact diameter and the dividing is again a matter of micrometer and microscope, of master screws and other highly specialized and refined equipment. The amateur takes a strip of flat metal, scribes on the divisions by the aid of a long screw such as the lead screw of a lathe and a clock dial, stamps or etches the division numbers, joins the two ends, turns, cuts or files a circular centrepiece to fit the resulting diameter, solders the divided rim onto it and his

circle is made. And, for the observer who uses his circles chiefly for finding purposes the result is as satisfactory as the most refined professional job.

It is not intended to imply that the amateur job necessarily will be the equal of the professional, either in appearance or accuracy, nor that the handicaps mentioned afford any excuse for slovenly work. By no means. But if carefully designed and constructed, the amateur's mounting will be far more satisfactory than the makeshifts too frequently seen and such that thoroughly sound work may be done with it.

II

Before discussing specific designs, perhaps some general matters may be briefly considered, not only for the sake of completeness but because they may serve to remove the very common notion that, compared with an alt-azimuth, the equatorial mounting is an exceedingly complicated mechanism. Essentially there is no difference.

The conditions to be met in any steady and convenient mounting are that, (1) the telescope can be pointed easily and quickly in any necessary direction, and (2) that it can be easily moved to follow accurately any moving object such as a ship or an aeroplane or a star. The first of these conditions requires that the support contain two axes set at right angles, giving a sort of universal joint action; the second, that these axes be so arranged as to require the least manipulation of the telescope when following the moving object.

Two general forms of mountings have been developed from these principles to meet the requirements of practice:

1. The alt-azimuth, most convenient for observing terrestrial objects and for measuring vertical and horizontal angles as required in the work of the land surveyor and civil engineer.

2. The equatorial, most convenient for observing celestial objects and for measuring angles in equatorial coordinates, as required by the work of the astronomer.

Both mountings have the same principal parts:

(1) A main axis carrying at right angles to it

(2) a secondary axis on which

(3) the telescope is mounted so that it can turn in a plane at right angles to the secondary axis.

A simple model of this arrangement will be of great help in following this discussion and can be easily and quickly made thus:— Roll a small tube of paper, say $\frac{3}{8}$-in. diameter by 4-in. long to represent the telescope. Bend a piece of wire to a right angle with one leg about 1-in. long, the other about 2-in. long. Push the short leg, which represents the secondary axis, transversely through the paper tube and the long leg, which represents the main axis, through the two ends of a flat U-shaped piece of cardboard as in Fig. 1a. From this model it will be clear that the two motions it provides,

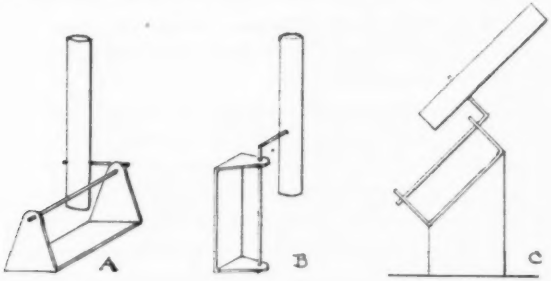

Fig. 1.

namely, the telescope swinging in its bearings and the main axis turning in its bearings, enable the telescope to be pointed in any necessary direction.

If the model be stood on end so that the main axis is vertical as in Fig. 1b, we have an alt-azimuth mounting. To be able to point the telescope in any desired direction or to find the bearings of any object *from the position of the telescope*, two graduated circles are used, one on the main axis for measuring horizontal angles from, say, the south point of the horizon or other definite point, the other on the secondary axis for measuring the vertical angle, say, from the zenith or from the plane of the horizon. Of course, since these reference points change as the observer changes his position, the angles so measured will be correct only for a particular position of the telescope and, if the object be moving, only for the

particular instants when the measurements were made. The engineer's transit is the conspicuous example of an alt-azimuth mounting.

Before considering the equatorial mounting it is well to recall that the position of a celestial object is given by stating its right ascension and its declination. Its right ascension is the interval of sidereal time, as the earth rotates on its axis, between the transit across the meridian of the vernal equinox and of the object observed. Its declination is the angle in the sky, measured at right angles to the plane of the equator, between the celestial equator and the object. As the plane of the equator is used as the principal plane of reference in this system, these are known as equatorial co-ordinates. Clearly these co-ordinates, unlike those used with an alt-azimuth, are independent of the observer's position on the earth and of his time of observation.

Evidently then, if the main axis be set parallel to the earth's axis by tilting the mounting as in Fig. 1c, the telescope can be used to measure directly the position of an object in these co-ordinates, or these co-ordinates can be used directly to set the telescope on an object. In consequence, a mounting so arranged is called an equatorial mounting.[6] As the main axis now points to the celestial pole it is named the "polar axis". Similarly, the secondary axis is named the "declination axis", for, being at right angles to the polar axis, it lies in the plane of the equator, that is, at zero declination, and as the telescope can be set at any angle with that plane, that is, at any declination, it will sweep out in the sky the circle of the declination for which it is set when the polar axis is rotated.

The essential difference then between the alt-azimuth and equatorial mountings lies simply in this difference of inclination of the main axis. In the alt-azimuth it points to the zenith; in the equatorial, to the celestial poles. Both enable a star to be followed throughout its passage across the sky, but whereas two

[6]The idea for an equatorial mounting seems to have originated with one Christopher Grienberger, S.J., of Rome, who, about 1612, suggested it to Christopher Scheiner, S.J., as a means of avoiding difficulties Scheiner was having in observing accurately positions of sunspots with his alt-azimuth. See W. M. Mitchell's "History of the Discovery of Sunspots", *Pop. Ast.*, vol. 24, 1916.

adjustments, each of varying amount must be made continuously if the telescope be mounted as an alt-azimuth, with an equatorial mounting one of these adjustments reduces to a simple setting of the telescope to the declination of the object to be observed and the other to a uniform rotation of the polar axis to compensate for the uniform rotation of the earth.

To enable an object to be found from its right ascension and declination the two axes are fitted with graduated circles as in the alt-azimuth. As a matter of convenience however, the manner of graduation differs from the circles of an alt-azimuth. As declination is expressed in degrees north or south of the equator, the declination circle is graduated similarly and is set to read 0° when the telescope is in the plane of the equator and 90° when it points to the celestial pole. Thus the reading of the circle corresponds to the declination of the object. Right ascension being ordinarily expressed in time instead of in degrees, it is convenient to graduate the circle on the polar axis into 24 equal parts or hours, hence its name "hour circle".

The distance of an object east or west of our meridian can then be found at once, for the time that has elapsed since the vernal equinox last crossed our meridian is our sidereal time and the difference between our sidereal time and the right ascension of the object is its distance measured in time from our meridian, and hence, its "hour angle"; west when its right ascension is less than our sidereal time, east when its right ascension is greater.

III

The difficulty of figuring the hyperbolic mirror of the Cassegrain reflector deters all but the boldest and most experienced of amateurs from attempting it. Since these notes are not intended for such expert constructors and as, for the great majority of us, the Newtonian remains the telescope *par excellence*, the discussion which follows applies chiefly to mountings suitable for that type of telescope.

In the practical development of the equatorial mounting the three elements: polar axis, declination axis and telescope may be arranged in a number of ways. Each has its advantages, all have the defects of their qualities.

The most usual of these arrangements are the four shown in Fig. 2. In this figure, types A and C are drawn with the declination axis vertical, corresponding to an hour-angle of 6 hrs.; types B and D with the declination axis horizontal, and the telescope is then in

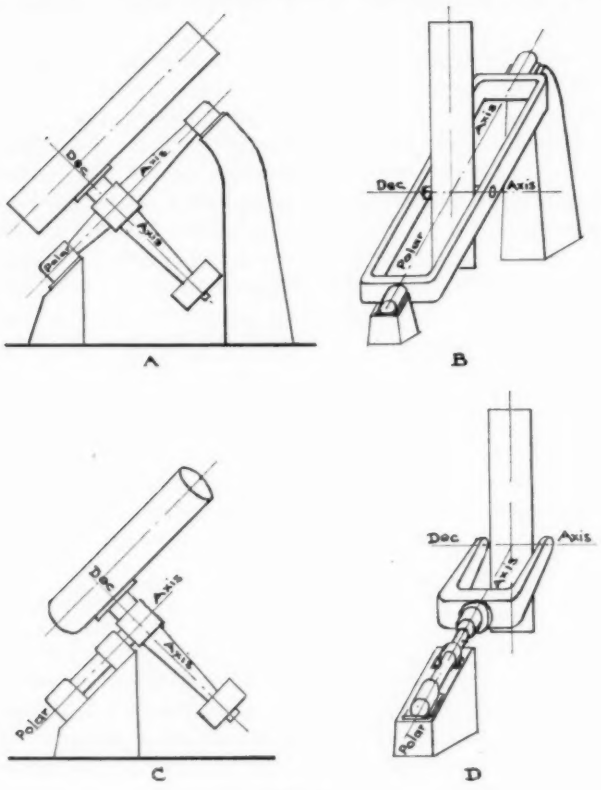

Fig. 2.

the meridian, the hour-angle is zero. In A the telescope is directed towards the celestial pole, declination +90°; in B and D to the zenith, declination about +45°, and in C to a point about half way between, declination +68°.

From the country where the principal development of the design took place, types A and B are commonly known as English mountings, and type C as the German mounting. Type D, commonly called the "fork" mounting is also an English design. To prevent confusion, type B, a direct descendant of the parallactic ladder of early days in England, is perhaps better termed the "yoke" mounting.

In type A the polar axis is a beam and in B a pair of beams supported at the ends and loaded near the middle. In types C and D it is a cantilever, a beam held at one end and loaded at the other. Structurally, for equal dimensions the supported beam is sixteen times as stiff as the cantilever. It follows that in types C and D it is important to keep the overhang as short as possible, to reduce sag or bending to the lowest practical limit. In this respect type C obviously is stiffer than type D. On the other hand, the type D mounting allows the telescope to follow a star across the meridian without interruption whereas in type C as usually constructed the telescope must be reversed when passing the meridian. This is not important except where the telescope is to be used largely for photography. The objection can be avoided by the use of an overhung polar axis as was employed by Messrs. Warner and Swazy for the 12-in. Bruce telescope of Yerkes Observatory, Fig. 3 (Plate XXV). But of course this advantage is gained only at the expense of very heavy supports to ensure stability.

A short overhang is of course desirable also in the declination axis in types A and C to reduce the amount of counterbalance weight necessary and correspondingly the load on the polar axis and its bearings. Owing to the balanced arrangement of the telescope in types A and C, the load on the polar axis in those types is constant in amount and direction for all hour-angles. In types B and D which are designs made to get away from the extended declination axis and cumbersome counterpoise of types A and C, the load is borne equally by both members of the polar axis only when the telescope is in the meridian as in the figure. As the telescope passes from an hour-angle of 6-hrs. east to 6-hrs. west, the load at first is all borne by one member and is gradually trans-

ferred until it is all borne by the other member of the polar axis. What bending or sag may result from this changing load consequently affects the position of the telescope axis first in one direction and then in the other. This condition is particularly the case in the type D or fork mounting where the need for guarding against such displacements due to inequality of loading involves a very heavy structure for the fork. In type B the north bearing of the polar axis prevents observation of a considerable area around the pole. In type A there is no blind spot because the axis of the telescope is never coincident with the polar axis. In the 100-in. at Mt. Wilson this defect of the type B mounting is exaggerated by the large diameter of the mercury float bearings used. The completely successful use of roller bearings, first in the 72-in. Victoria, B.C., telescope and in all large instruments since, warrants the belief that mercury float bearings would not be used were this mounting to be built to-day.

An ingenious modification of the yoke, type B, has been developed by a California amateur, Dr. H. Page Bailey. In this design, Fig. 4 (Plate XXVI), instead of being brought together to the usual single bearing as is done at the lower end, the upper ends of the two side-pieces are carried in a ring from which a segment is omitted,[7] thus eliminating the blind area around the pole. The ring is carried on two roller bearing supports one on each side and slightly below the polar axis. Small counterbalance weights compensate for the missing portion of the ring. The polar axis is thus supported at three points which makes for steadiness and balance at any position of the telescope. It is claimed for this mounting that it "overcomes the disadvantages of the German, fork, and English (yoke) types. Unlike the German mounting it is not necessary to reverse the telescope in following a star across the meridian. The inequalities of sag inherent in a fork mounting are replaced by uniformity in all directions so that the tube always

[7]The split ring appears to have been employed first by R. W. Porter who described such a mounting in an article in *Pop. Ast.*, vol. 26, p. 147, 1918, and subsequently patented the device. It is said however to be a much earlier arrangement.

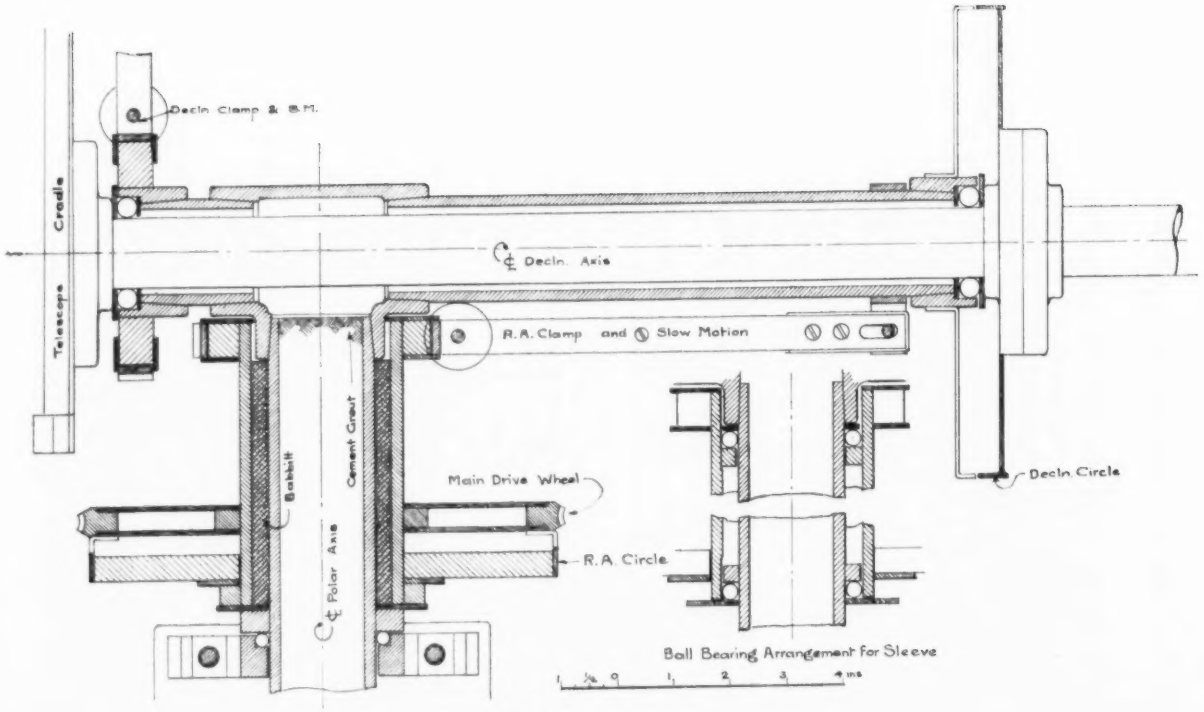

Fig. 5. German Mounting.

remains parallel to its own axis, and the stability of the English type is maintained with the addition of accessability to the polar stars".[5] In writing about this mounting Dr. Bailey says: "I had tried practically all the known mountings and was not satisfied with any. It suddenly occurred to me that if I could push down the N. cross-arm of the double yoke mounting, getting at the pole, it would be ideal. This mounting was the result." It was first used for a 15-in. Cassegrain reflector by Dr. Bailey and was then adopted for a 24-in. for the Junior College at San Bernardino, Cal., where it has been in successful use for some five years.

The yoke and fork types have the advantage that the telescope is in the axis of the dome. This enables the diameter of the dome and the desirable width of the shutter opening to be reduced materially, reducing also the cost and weight and the extent of movement of the dome needed.

For instruments of an aperture up to 12 inches probably the German mounting will be found quite satisfactory. A simple mounting of this type suitable for a telescope weighing not over about 35 lbs. is shown in Fig. 5. Using inexpensive, readily obtained materials and but few if any special castings, it is believed that the conditions of design—a steady and convenient mounting of low material cost and ease of construction—have been met. Of course these advantages are at the expense of a somewhat greater amount of labour. Great manual skill, however, is not so requisite as care and patience.

The declination axis is of "extra strong" black pipe; the declination axis housing and the polar axis are of "standard weight" black pipe. These may look a little light, but adequate mass and stiffness are obtained by filling both axes with portland cement one volume, clean sand two volumes with water to make a grout that will just pour easily. In two or three days this sets solid and continues indefinitely to harden.

Provided the one is square with the other, the connection between the declination housing and the polar axis may be made in various ways:

[5] *Popular Astronomy*, vol. 39, p. 497, 1931.

(1) By welding the two together.

(2) By using three pieces of pipe screwed into a tee as shown.

(3) By using a single piece of pipe for the declination housing as in method (1), but passed through the run of the tee which is one pipe size larger than the housing. By four no. 10 screws in each end of the tee the housing is set true and square with the polar axis which is threaded and screwed into the outlet of the tee as in no. 2. When the two are properly adjusted the polar axis and the space around the housing within the tee are filled solidly with the cement grout holding both pipes permanently in place.

Of these methods no. 3 is probably the most satisfactory as it permits accurate adjustment for "squareness" which here is necessary. For this reason also pipe threads are best cut in the lathe, failing this in a pipe machine carefully set. Hand-cut threads are never reliable as to "squareness".

Both axes are run in plain ball bearings, the best and simplest to make. Separators are not needed between the balls, simply as many balls are dropped into the race as it will hold without crowding. The races for the declination housing are made from halves of standard pipe couplings, those for the polar axis bearings from standard shaft collars.

The main drive wheel, hour circle and right ascension clamp drum are carried on a sleeve on the polar axis. Determined by the drive to be used, the main drive wheel has either a simple groove on its rim or a worm cut in it, in which case it must be a brass casting. The hour circle, turning freely on the sleeve, is set to read sidereal time when starting to observe. Then, the driving mechanism keeping reasonably accurate speed, the telescope is set and clamped in declination and the polar axis is rotated until the hour circle reads the right ascension of the object and is then clamped. Calculation of the hour angle is not needed. Final adjustment is made while at the eyepiece by the slow motions fitted for both co-ordinates.

The free hour-circle, due to Sir George Airy, is a most convenient device. Two pointers are required for it. One, *a*, is secured to

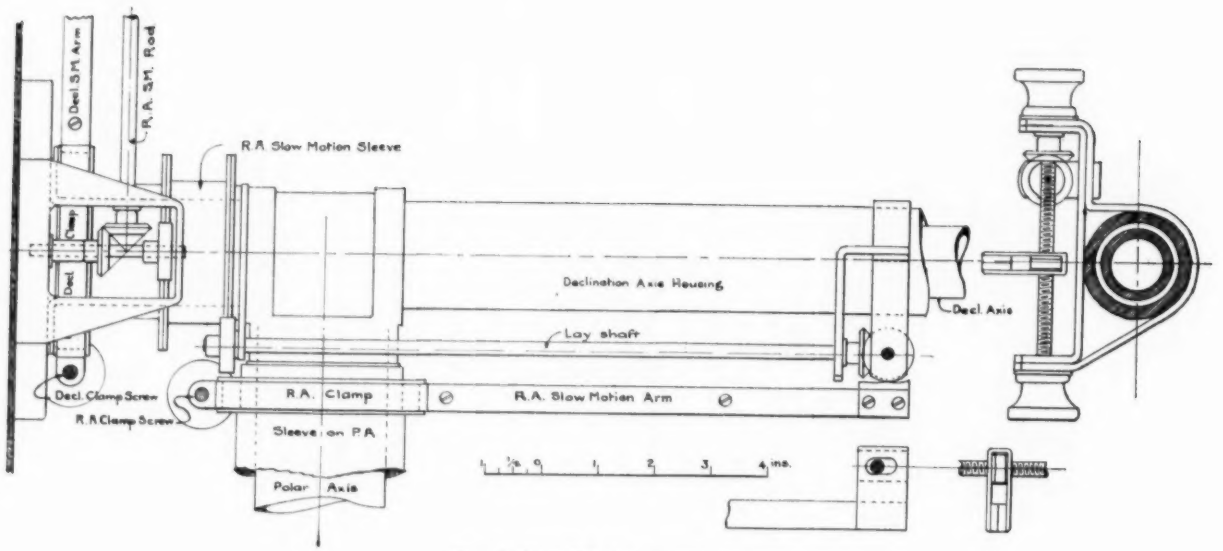

Fig. 6. Slow Motion Operators.

the polar axis, the other, *b*, to a stationary part of the mounting. The method of use with a continuously driven telescope was mentioned above. When the telescope is simply hand-driven the hour-circle is better carried directly on the polar axis. Then in setting, the circle is turned until the right ascension of the object is under pointer *a*; the polar axis is then rotated carrying the circle round with it until the figure corresponding to the sidereal time is under pointer *b*. In either arrangement the pointers are correctly placed if, when the telescope is in the meridian, both indicate the same time or the same time ± 12 hr.

In Fig. 5, the slow motion in right ascension is transferred to near the eyepiece by a short flexible shaft. If the slight springiness unavoidable in the flexible shaft is found annoying, recourse may be had to a system of gears carried on a sleeve on the declination axis housing and operated by bevel gears as shown in Fig. 6 or by a rod connected through universal joints.

Round-headed screws are used throughout so that if a hole is drilled slightly out of position it can be filed out to allow the screw to enter and seat; with flat-headed screws this is not so easy. A word of warning: do not try to tap holes in iron or steel for less than a no. 8 screw, a tap broken and stuck fast in the hole is almost sure to result.

The clamp drums can be castings, faced, turned and drilled if desired, but they will be quite satisfactory if made of two thicknesses of hard wood placed with the grain crossed, glued and screwed together and thoroughly shellacked. The rim may be fitted with a tin liner screwed on to take the little wear there really is.

An interesting development of the use of the sleeve on the polar axis, due to Mr. F. L. Prescott, is illustrated in *Scientific American*, Sept., 1936, p. 166. In this design the sleeve becomes a long hollow shaft which runs in the main bearings and forms a housing for the polar axis proper which turns in bearings in the ends of the sleeve. The drive is at the lower end which reduces the overhang of the declination axis.

(To be continued)

EVOLUTION OF THE SOLAR SYSTEM

At the recent meeting of the British Association at Blackpool there was a discussion on the above subject in which the following took part: Prof. A. Holmes, Prof. E. A. Milne, Prof. W. H. McCrea in the absence of Mr. R. A. Lyttleton, Prof. V. Bjerknes, Dr. Harold Jeffreys. The following summary of the discussion, signed by "W. H. McC", appears in *Nature* for September 26, 1936.

No theory of the origin of the solar system has yet gained general acceptance. Indeed, until quite recently, none existed which satisfied all the following simple general tests: it should explain (i) the production of satellite systems as well as the planetary system; (ii) the regularities in the sequence of the planetary masses, of the ratios of the masses to those of the largest corresponding satelites, and of the numbers of corresponding satellites, when the planets are arranged in order of distance from the sun; (iii) the birth of the system at an epoch when the physical constitution of the sun was not greatly different from what it is at present; (iv) the large amount of angular momentum possessed by the outer planets.

Arranging the chief theories in the order of the number of bodies involved in the birth of the system, we have first Laplace's nebular hypothesis. The origin is sought in the cooling, and consequent shrinkage and speeding up of the rotation, of a single nebular mass of gas extending initially beyond the orbit of the outermost planet. The planets are supposed to be formed from rings of matter thrown off in the process of shrinkage; but there is a failure to explain how such rings could condense into planetary form, or how they could possess the observed amount of angular momentum even were the condensation achieved.

Laplace's theory is found, in fact, to involve an insufficient number of adjustable parameters. So various subsequent theories (Buffon, Proctor, Bickerton, Chamberlin and Moulton, Jeans, Jeffreys) have appealed to the intervention of a second body. Some twenty years ago, Jeans proposed his tidal theory, which at the time was the most successful in this category. A second star was supposed to have described a hyperbolic orbit about the sun

and it was shown that, if the approach had been sufficiently close, the tides raised in each body by the gravitational pull of the other would have become unstable and grown into a great filament of gas in the space between the two. The gravitational instability of this gas would cause it to condense into planetary masses, some of which would be retained in the gravitational field of each of the two stars. This theory is particularly successful in explaining the regularities noted under (ii), but, as Jeffreys and H. N. Russell have pointed out, and as its author admits, it again encounters difficulties with regard to the peculiar distribution of angular momentum. Some of the difficulties Jeffreys has tried to remove by imagining a still closer encounter of the two stars than Jeans had postulated.

Russell was the first tentatively to suggest that three bodies had been concerned in the production of the solar system, by supposing that the sun was originally a double star, and that the planets were formed by an intruding star encountering, not the sun itself, but its original companion. The actual production of planets by the encounter would be supposed to proceed as on Jeans's theory, but it would now clearly be possible to account for their large angular momentum about the sun, or, what comes to the same thing, their large distance from the sun. Russell himself saw difficulties in explaining how the companion and intruder could both escape from the sun after the encounter, and still leave the planets entangled in the sun's field. R. A. Lyttleton, however, independently put forward the same hypothesis, and at the same time showed that these difficulties are not inherent in it. He has demonstrated that, for ranges of real values of the initial velocities of the bodies involved, it is possible for the encounter of the companion and the intruder to communicate velocities to them which carry them both "to infinity" in different directions, while parts of the tidal filament formed between them, and endowed with velocities intermediate between those of the escaping stars, would have velocities insufficient to get away from the gravitational field. Further, this may happen for initial velocities of the intruder relative to the sun of the same order of magnitude as the observed relative velocities of stars in the same neighbourhood of the heavens.

The theory can be developed to account for the similar sense

of revolution of the planets round the sun, for their rotations, and for the existence of satellites. The latter are supposed to be formed by tidal encounters of pairs of planets when, in their revolution round the sun, they both arrive back simultaneously in the same neighbourhood as where they were originally formed. That they should do so before they have had time to condense appears improbable, and this is one of the objections that have been raised against the theory. Nevertheless, so far as Lyttleton's theory has been worked out—it is still in its early stages—it does seem capable of accounting for all the *dynamical* features of the solar system.

Geology cannot say anything about the origin of the earth, but from radioactivity data it can set a well-established lower bound to its age. The generally accepted theory of the formation of rocks has indicated where the oldest exposed examples are to be found, and the lead-ratio method has shown these to be about 2000 million years old, but their constitution shows them to have been made, by weathering and fusion, out of still older rocks. However, combining this information with that got by Paneth concerning the age of meteorites as given by their helium content, we are led to the figure of about 2700 million years as the age of the solar system. Geological evidence based on seasonal effects preserved in the structure of the varved clays, and on the recurrence of glaciations, shows further that there have been no large changes in the dynamical and thermodynamical relations between the earth and the sun for something like 2000 million years.

A study of the chemical composition of the planets leads to many grave difficulties, as Jeffreys has emphasized. For example, in the case of the outer planets, the order of increasing mass is the order of decreasing density, which seemingly admits the explanation that when the masses were gaseous the stronger gravitational fields were better able to prevent the lighter elements from diffusing away into space. But now for the inner planets, Mercury, Venus, Earth, Mars, and also the moon, the order of increasing mass is the order of *increasing* density, which is inconsistent with any such simple explanation. Again, the earth consists of a rocky shell of mean density about 3.3 and a central liquid (probably iron) core of mean density about 12. The mean density of the whole moon, on the other hand, is about 3.3, so that it

evidently does not possess a heavy core. This suggests that, if the moon was formed by the breaking up of a planetary mass, then it took place after the heavy elements in the latter had had time to settle down towards the centre, indicating that the formation of the satellite took a considerable time. However, most theories of the formation of satellites require them to have been formed very early in the history of the planets. Also it is difficult to explain how the earth retained any light elements unless its crust solidified very quickly, and it is then difficult to see how the moon could have been formed after solidification. In fact, in the present state of the theory, any explanation of one feature of the chemical composition of the solar system appears to be contradicted by some other feature.

The difficulty about the angular momentum of the system has been mentioned. Lyttleton's theory is the most successful attempt hitherto made to resolve it on the basis of ordinary mechanics. There may still be other ways; for example, E. W. Brown has pointed out that the theory of the perturbation of one planet by another might lead to an exchange of angular momentum between them, if it were carried to a higher degree of approximation than is usually done. But a much more fundamental resolution of the difficulty is now put forward by E. A. Milne on the basis of his recent work on the foundations of dynamics. In this work he starts from observers' immediate consciousness of *time*, and their description of motion based thereon, and is able to derive the forms of the laws of dynamics and gravitation from purely kinematical considerations. He postulates the equivalence of observers in regard to their observation of each other and of the rest of the universe, but he does not need to appeal to experience for any empirical "laws of motion" or of "gravitation". His results are derived first in terms of *kinematical time* t. He then finds that they pass over into the local empirical Newtonian forms on transforming to *dynamical time* τ, where $\tau = \log (t/t_0) + t_0$, and t_0 is the present value of t obtained from the expansion of the universe. The value of t_0 is about 2×10^9 years, which is also about the age of the solar system given by radioactivity data.

So this would place the origin of the solar system at about the singular epoch $t=0$ occurring in the kinematical theory. If the

correspondence were exact, then, since $\tau \to -\infty$ when $t \to 0$, the age of the system, reckoned by dynamical events, such as the revolution of a planet round the sun, would be infinite. In other words, in dynamical time the solar system never had a beginning. This suggests a reconciliation between the "short" and "long" time scales, which have presented inconsistencies in connection with many cosmological problems.

Another consequence of the theory is that angular momentum is not a time invariant, but the angular momentum of any local system grows at a rate proportional to itself. Thus small initial differences of angular momentum tend to be magnified as time goes on. This would remove difficulties connected with the rotation, not only of the solar system, but also of spiral nebulae, in which the amount and distribution of angular momentum has long been a puzzle. It should be added, however, that this theory also has yet been given only a preliminary form.

THE PHYSICAL STATE OF THE UPPER ATMOSPHERE

By B. HAURWITZ

(Continued from page 366)

VII. THE AURORA

Aurorae appear in many various forms which are not sharply distinct but merge into one another. Three examples of aurorae, taken by C. Störmer in Norway are reproduced in figures, 11, 12 and 13. For a detailed study of the different types the "Photographic Atlas of Auroral Forms" is recommended[60].

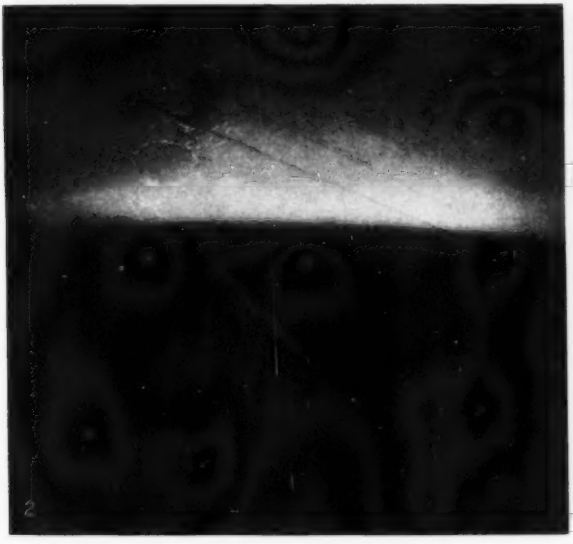

Fig. 11.—Homogeneous arc, Kongsberg, Oct. 16-17, 1923. Phot. Störmer (Erg. kosm. Physik, vol. 1).

The geographical distribution of the aurora over the northern hemisphere is shown in fig. 14. The distribution over the southern hemisphere is probably similar, but the observations are still too scanty to say anything definite[61]. The map shows that the lines of equal auroral frequency are roughly circles not around the magnetic pole, but around the point where the axis of the magnetic dipole,

which approximates to the earth's magnetic field, intersects the surface of the earth. The frequency of auroral displays increases towards the north, reaches a maximum and then decreases again. In more southerly locations aurorae are of course seen mostly in the northern sky. There is, however, inside the circle of maximum frequency, a zone where no direction is particularly favoured (broken line in fig. 14).

Fig. 12.—Homogeneous band, Korsnes, March 15-16, 1913. Phot. Störmer (Erg. kosm. Physik, vol. 1).

The development of the measurement of auroral heights is mainly due to C. Störmer[62]. Photographs of the same aurora are taken simultaneously from two or more stations. The angular height and azimuth of the aurora can be determined from these plates, which give the apparent position of the aurora among the

stars. It is then easy to find the actual position of the aurora in space.

Störmer's results from 1911 to 1922 are summarised in fig. 15. Measurements during other periods have given the same results. The lowest heights of aurorae in Norway were about 80 km.; maxima of frequency occur at 101 and 106 km.; higher up the frequency

Fig. 13.—Corona, Oslo, Dec. 16-17, 1917. Phot. Störmer (Erg. kosm. Physik, vol. 1).

decreases again. Sometimes aurorae have been reported very near the earth's surface but exact measurements do not confirm these reports. It seems that such observations may be attributed to an understandable optical illusion.

The two maxima of auroral frequency are explained by Egedal[11] as due to atmospheric tides. It will be seen later that aurorae are caused by electrically charged particles from the sun which enter

the atmosphere and cause the luminescence of the upper rarefied atmosphere in a manner similar to cathode rays in a discharge tube. The depth of penetration of these particles evidently depends on the density of the atmosphere and this in its turn is affected by the atmospheric tides, as we had already seen in the case of the meteors (p. 323).

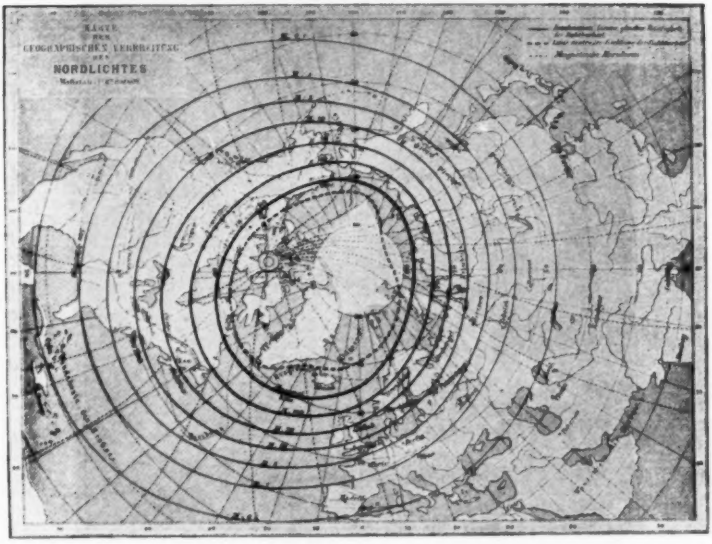

Fig. 14.—Geographical distribution of auroral frequency, after Fritz. (Erg. kosm. Physik, vol. 1).

Determinations of the height of the aurora in Canada were made by Alty and Wilson at Saskatoon[63], by Currie at Chesterfield Inlet[64] and by McLennan, Wynne-Edwards and Ireton[65]. The mean lower height limit of the quiet forms was found at about 105 to 110 km., which is similar to the observations made in Norway. Alty and Wilson found the lowest aurora at 59 km. altitude, considerably lower than that found in Norway.

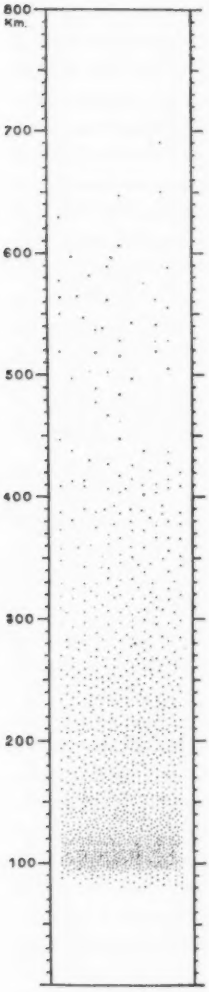

Fig. 15. — Auroral heights in Southern Norway, 1911-1922, after Störmer (Erg. kosm. Physik, vol. 1).

Fig. 15 shows that aurorae have been observed up to altitudes of 650 km. In rare cases the height of the aurora is still higher, as for instance that on Sept. 8, 1926[62, 66]. Fig. 16 shows the position of this aurora in space according to Störmer's measurements. The full straight line represents the boundary between sunlit and dark atmosphere (refraction disregarded). The points of the aurora which were actually measured are shown by black dots. The greatest part of the auroral rays lies in the sunlit atmosphere and at much greater heights than the aurora is found in general. The highest points measured are well above 1,000 km. Two rays are seen in the earth's shadow. They appear to be extensions of sunlit rays which are interrupted at the boundary of the earth's shadow. It seems that the transition from rays illuminated by the sun to those not illuminated occurs quite suddenly between 1,700 and 2,300 km. east of the point of sunset at the surface, as illustrated by observations on March 22-23, 1920, and May 13-14, 1921. The colour of these sunlit aurorae is not greenish like that of the aurora in the dark atmosphere but rather blue to violet or grey-violet. In agreement with this the spectroscopic observations show that in the sunlit aurora the green line of 5577A is much less intense as compared to the nitrogen lines 4278A and 3914A[62] (cf. p. 327). According to Vegard and Tönsberg[67] the "red" oxygen line 6300A is 4 to 5 times stronger relative to the green line in the sunlit than in the dark atmosphere. They explain this by the action of the molecular nitrogen on ozone in the sunlit atmosphere.

Ozone is supposed to be more abundant in the sunlit atmosphere which would account for the enhancement of the oxygen line 6300A. A qualitative discussion of the possibility of this explanation, which would compare the observed intensity with the possible frequency of the reaction in the atmosphere, has not yet been given.

We have already anticipated the discussion of the auroral spectrum by describing the spectrum of the rather rare aurorae in the sunlit atmosphere and the spectrum of the night sky. It was mentioned that the outstanding difference between the night sky and auroral spectra is the greater faintness of the N bands in the

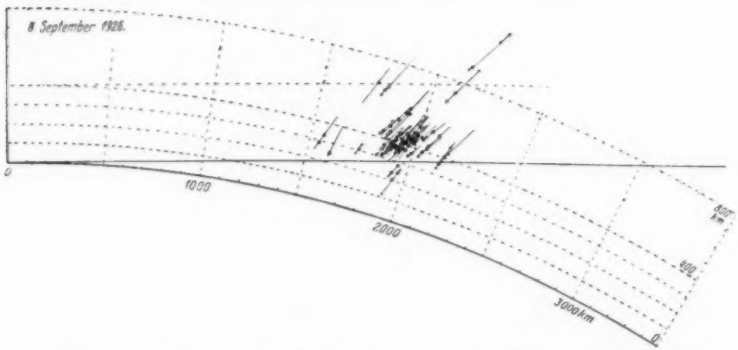

Fig. 16.—Sunlit aurora of Sept. 8, 1926, after Störmer (Erg. kosm. Physik, vol. 1).

former than in the auroral spectrum (cf. p. 327). Both spectra definitely indicate the presence of oxygen and nitrogen, while they do not show definitely that lighter gases are absent. Vegard attempted to determine the temperature of the auroral region from the intensity distribution in the rotational series of the negative nitrogen bands[68-71]. He obtained 225.4°K. as a most probable value. Rosseland and Stensholt[72] found a temperature of 347°K. from the same hypothesis, showing that the method at present is not very reliable.

If the aurora is the result of the intrusion of electrons in the high layers of the atmosphere, the fact that the aurora is higher in the sunlit than in the dark atmosphere would indicate a greater density

of the atmosphere at any level during the day than during the night, since the effective distance of the corpuscular rays will remain the same. Angenheister[73] has published an estimate of the daily temperature variation in the auroral layers from the observed auroral heights interpreting the hypothetical density variations as caused by temperature changes. He found that the best agreement with the observations is reached if the atmosphere between 100 and 200 km. is heated from 300° to 1000°K. during daytime, while above 200 km. the heating is less pronounced. One hundredth of a millimetre of ozone in these altitudes—the total amount of ozone in the atmosphere is about 3 mm. under N.P.T.—would be sufficient to raise the air temperature to the computed amount.

Vegard, on the other hand, has suggested that the expansion of the high atmosphere as evidenced by the sunlit aurora might be due to an electrostatic field in these layers[74].

Recently, the vertical motions of the upper atmosphere, as evidenced by the height of the aurorae, and also by the propagation of radio waves, have been studied by Harang[73a]. But our knowledge of these phenomena is still not sufficiently complete to give reliable numerical values.

The close relation between magnetic storms and aurorae has already been mentioned in the previous chapter. Since magnetic disturbances and sunspots are closely correlated, there exists also a clear connection between sunspots and aurorae. In many cases, when a large sunspot passes the central meridian of the sun, auroral displays are reported even from stations well outside the zone of maximum auroral frequency. The eleven-year sunspot period is clearly found in the frequency of the aurorae.

Goldstein and Birkeland were the first to propose the hypothesis that aurorae are caused by electrically charged particles emitted by the sun which, under the influence of the earth's magnetic field, describe certain orbits around the lines of magnetic force and cause the light phenomena which we call aurorae in the rarefied upper atmosphere. This theory would explain the correlation between solar activity and aurorae. Since the electrically charged particles moving in the earth's magnetic field cause magnetic phenomena the correlation between magnetic storms and aurorae would also be accounted for. Birkeland supported the theory by experiments in

which a magnetized sphere was bombarded by cathode rays. The sphere was impregnated with a substance which emitted light under the bombardment of cathode rays. The maximum of luminosity was found on a ring around the magnetic axis of the sphere, closely resembling the zone of maximum frequency of aurorae.

C. Störmer, in a great number of papers[62], has studied the motion of an electrically charged particle in the earth's magnetic field from a mathematical view-point. The actual computation of the orbits is rather complicated. Some fundamental results can be derived fairly easily, however, and will be given here. It is necessary to make a number of simplifying assumptions in order to obtain a solution of the problem. If we start with the Gaussian development of the field of terrestrial magnetism we find that the first term in the series becomes the more dominant the farther away we are from the earth. We neglect therefore the terms of higher order, which means that the magnetic field of the earth is approximated by a sphere of homogeneous magnetization, or a dipole. The magnetic axis intersects the northern hemisphere near Smith's sound in Northern Greenland. If we choose the axis of the dipole as z-axis the potential is

$$-\frac{\partial}{\partial z}\left(\frac{M}{r}\right),$$

where M is the magnetic moment. The components of the magnetic force, obtained by partial differentiation, are found to be

$$H_x=-M\,\frac{3xz}{r^5}\,,\quad H_y=-M\,\frac{3yz}{r^5}\,,\quad H_z=-M\,\frac{3z^2-r^2}{r^5}\,. \tag{17}$$

where $r^2=x^2+y^2+z^2$.

We assume further that the particles move so rapidly from the sun to the earth that their relative position does not change on the way. A third assumption is that long thin rays of corpuscles exist which do not interact upon each other and are not dissipated by electrostatic repulsion. Finally, it is assumed that the earth's magnetism is the only external force and that solar magnetism, gravitation, etc., can be neglected.

The equations of motion of a particle with charge e and mass m in this magnetic field are

$$m\frac{d^2x}{dt^2} = e\left(\frac{dy}{dt}H_z - \frac{dz}{dt}H_y\right)$$

$$m\frac{d^2y}{dt^2} = e\left(\frac{dz}{dt}H_x - \frac{dx}{dt}H_z\right) \quad \ldots\ldots\ldots (18)$$

$$m\frac{d^2z}{dt^2} = e\left(\frac{dx}{dt}H_y - \frac{dy}{dt}H_x\right)$$

The system of equations (18) shows that the magnetic force is perpendicular to the velocity. Therefore the total velocity is constant, namely,

$$v = \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2 + \left(\frac{dz}{dt}\right)^2} \quad \ldots\ldots\ldots (19)$$

a result which can also be obtained by multiplying the three equations (18) by

$$\frac{dx}{dt}, \quad \frac{dy}{dt}, \quad \frac{dz}{dt},$$

respectively, and adding. Since v is constant we may introduce the line element ds instead of the time element dt by

$$ds = vdt,$$

and, on putting for abbreviation

$$c = \sqrt{\frac{Me}{mv}},$$

obtain

$$\frac{d^2x}{ds^2} = c^2\left[\frac{3yz}{r^5}\frac{dz}{ds} - \frac{3z^2-r^2}{r^5}\frac{dy}{ds}\right]$$

$$\frac{d^2y}{ds^2} = c^2\left[\frac{3z^2-r^2}{r^5}\frac{dx}{ds} - \frac{3xz}{r^5}\frac{dz}{ds}\right] \quad \ldots\ldots\ldots (20)$$

$$\frac{d^2z}{ds^2} = c^2\left[\frac{3xz}{r^5}\frac{dy}{ds} - \frac{3yz}{r^5}\frac{dx}{ds}\right]$$

The quantity c has the dimension of a length and if chosen as the new unit of length drops out of (20).

Introducing cylindrical coordinates

$$x = R\cos\phi,\ y = R\sin\phi,\ z = z,$$

the first two equations of (20) give, if the first is multiplied by $\sin\phi$ and subtracted from the second multiplied by $\cos\phi$,

$$\frac{d}{ds}\left(R^2\frac{d\phi}{ds}\right) = \frac{d}{ds}\left(\frac{R^2}{r^3}\right),$$

and, after integration,

$$R^2\frac{d\phi}{ds} = 2\gamma + \frac{R^2}{r^3} \quad \ldots\ldots\ldots\ldots\ldots (21)$$

where γ is an integration constant.

Multiplying the first equation of (20) by $\cos\phi$ and the second one by $\sin\phi$ and adding, gives

$$\frac{d^2R}{ds^2} = \tfrac{1}{2}\frac{\partial Q}{\partial R} \quad \ldots\ldots\ldots\ldots\ldots\ldots (22)$$

where

$$Q = 1 - \left(\frac{2\gamma}{R} + \frac{R}{r^3}\right)^2 \quad \ldots\ldots\ldots\ldots (23)$$

The third equation of (20) can be written

$$\frac{d^2z}{ds^2} = \tfrac{1}{2}\frac{\partial Q}{\partial z} \quad \ldots\ldots\ldots\ldots\ldots\ldots (24)$$

From (22) and (24) follows

$$\left(\frac{dR}{ds}\right)^2 + \left(\frac{dz}{ds}\right)^2 = Q \quad \ldots\ldots\ldots\ldots\ldots (25)$$

Putting a meridional plane E through the z-axis and letting it rotate so that the corpuscle is always in E, where its coordinates are R and z, we see that the motion in space consists of two parts

(1) the motion of the corpuscle in E given by (22), (24), (25).

(2) The rotation of E, given by (21).

Eq. (25) shows that Q can never become negative. Therefore

$$-1 \leqq \frac{2\gamma}{R} + \frac{R}{r^3} \leqq +1 \quad \ldots\ldots\ldots\ldots\ldots (26)$$

Thus, the regions in which the orbits of the corpuscles must be, are easily found. The space Q_γ which is characterized by a certain value γ of the integration constant is generated by

$$\frac{2\gamma}{R} + \frac{R}{r^3} = k, \quad \ldots\ldots\ldots\ldots\ldots (27)$$

where k increases from -1 to $+1$. If $R = r \sin \chi$, where χ is the angle between the magnetic axis and the radius vector r, we find

$$r = \frac{\gamma \pm \sqrt{\gamma^2 + k \sin^3 \chi}}{k \sin \chi} \quad \ldots\ldots\ldots\ldots\ldots (28)$$

The meridian curves of the surfaces which bound the space Q_γ are obtained by letting $k = +1$ and $= -1$. Some of these spaces are reproduced in fig. 17[75]. The left side gives meridional cross-sections through the surfaces, the right side shows the spaces themselves. The following will be seen from fig. 17. If $\gamma < -1$, Q_γ consists of two separate parts. For $0 > \gamma > -1$ these two parts unite and electrically charged particles can reach the magnetic dipole from infinity. There is, however, a toroidal space around the equator in which they cannot enter. The meridional curve of this space is according to eq. (28) given by

$$r = \frac{\sqrt{\gamma_1^2 + \sin^3 \chi} - \gamma_1}{\sin \chi} \quad \ldots\ldots\ldots\ldots\ldots (29)$$

where $\gamma_1 = -\gamma$. If $\gamma > 0$, the space Q_γ does not reach to the dipole and no particles can approach the magnet.

We see thus that Birkeland and Störmer's theory explains the appearance of the aurorae in polar regions since only there do the spaces Q_γ reach the dipole which we may regard as the earth. To compute the maximal angular distance χ_1, of the auroral zone from the magnetic axis we have to find the intersection of the toroidal surface with the auroral layer of the earth's atmosphere (fig. 18). Call the distance of the latter from the centre of the earth D (D is of course approximately equal to the earth's radius). Then from equation (29)

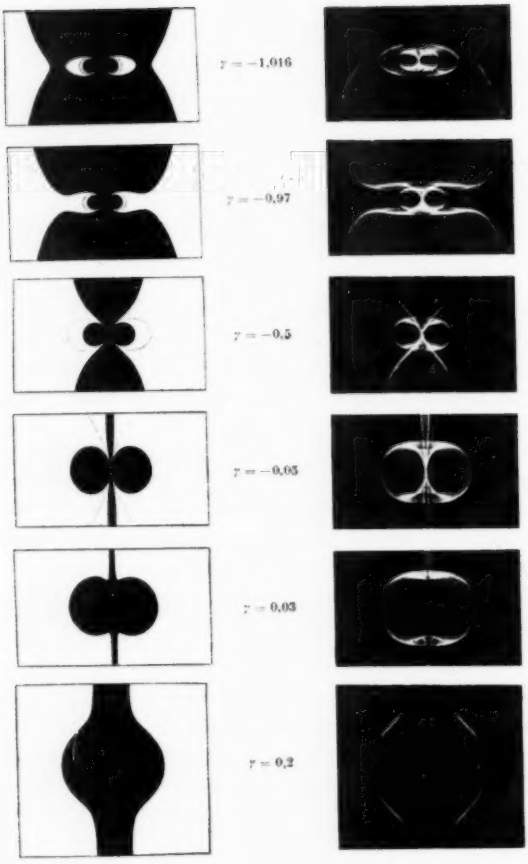

Fig. 17.—Spaces Q_γ which contain the orbits for various values of γ after Störmer (Erg. kosm. Physik, vol. 1).

$$\sin \chi_1 = \frac{D^2}{2} \pm \sqrt{\frac{D^4}{4} + 2\gamma_1 D}$$

Here the negative sign can be disregarded. Since we chose our unit of length c, which is much larger than D as we shall see presently, D is obviously very small so that we may write with sufficient accuracy

$$\sin \chi_1 = \sqrt{2\gamma_1 D},$$

or, since the maximum value of γ_1 is 1,

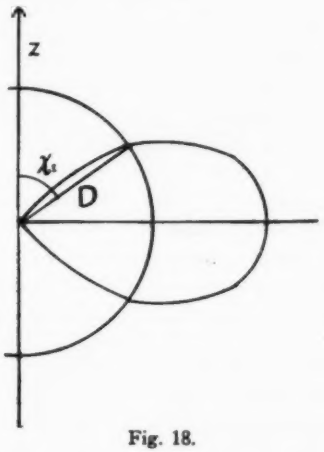

Fig. 18.

$$\sin \chi_1 = \sqrt{\frac{2D}{c}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (30)$$

where c has been introduced again in order to use the customary unit of length. In order to compute χ_1 from eq. (30) we have to know c. The magnetic moment of the earth was given on page 358.

Now, an electrically charged particle of mass m and charge e, moving perpendicular to the lines of a homogeneous magnetic field H with the constant velocity v, describes a circle of radius ρ where

$$v = \frac{e}{m} H\rho \quad \ldots\ldots\ldots\ldots\ldots\ldots (31)$$

which can be derived from eq. (18) or immediately written down as the equilibrium condition between centrifugal and electromagnetic forces (cf. eq. (15)).

Therefore c can be written

$$c = \sqrt{\frac{M}{H\rho}}$$

Krogness and Vegard[76] have observed auroral rays spiralling around the magnetic lines of force, going down and rising again. Near the turning points the path of the particle may be regarded as very nearly circular so that eq. (31) can be applied. In this way they found $H\rho < 15{,}000$ while Störmer estimated $H\rho < 10{,}000$. Since rays composed of positively charged particles would give much higher values for $H\rho$ it must be concluded that these auroral forms are caused by electrons, while others without ray structure are perhaps caused by positive particles. If $H\rho = 15{,}000$, we find from eq. (30), 7° only for the angular distance of the auroral zone from the magnetic axis, which is too small a value since fig. 14 shows that even the zone of maximal frequency has a much larger distance from the axis than this 7°. To explain this discrepancy Störmer pointed out that his computations showed that corpuscles which come from a practically infinite distance, as for instance from the sun, will move as a more or less circular current around the earth parallel to the equatorial plane outside the toroidal space into which the particles cannot enter. The magnetic attraction of this ring current causes the auroral zone to be deflected further south than would follow simply from eq. (30). Under ordinary circumstances the magnetic effect of this current is about 1,000 times smaller than the permanent field. If the electron emission from the sun is particularly strong and therefore magnetic storms occur on the earth, the intensity of this current increases and consequently its deflecting influence upon the zone of auroral displays becomes greater. Thus in the time of great magnetic storms aurorae are observed in much lower latitudes than usual.

The influence of the deflecting force of such an equatorial ring current can be verified experimentally. Fig. 19 shows such an experiment as carried out by Brüche[77]. That the auroral frequency

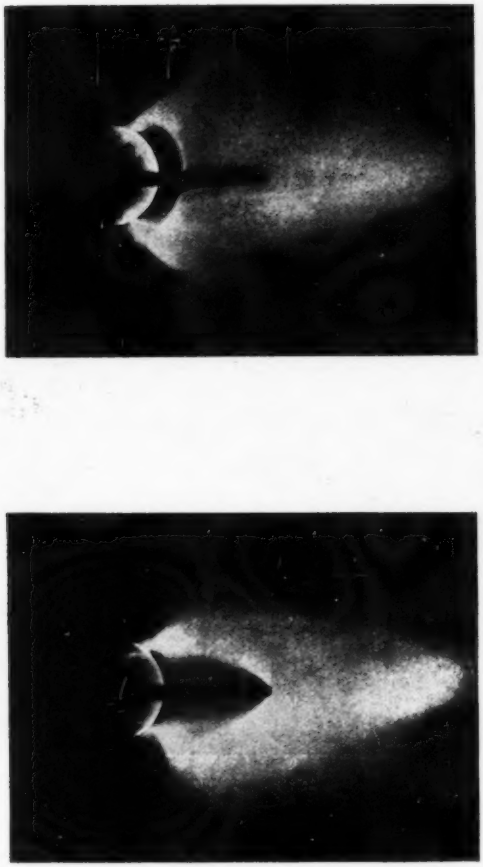

Fig. 19.—Influence of an equatorial ring current upon the position of the auroral zones, after Brüche. *Above*: without ring current; *below*: with ring current (Erg. kosm. Physik, vol. 1).

again decreases northwards from a zone of maximal frequency is easily understood if we consider that the smallest possible angle between dipole axis and direction from the sun to earth is 55°. Obviously then, orbits coming from infinity and having a direction less than 55° inclined against the dipole axis are out of the question.

Furthermore, the corpuscular theory of the aurora explains why

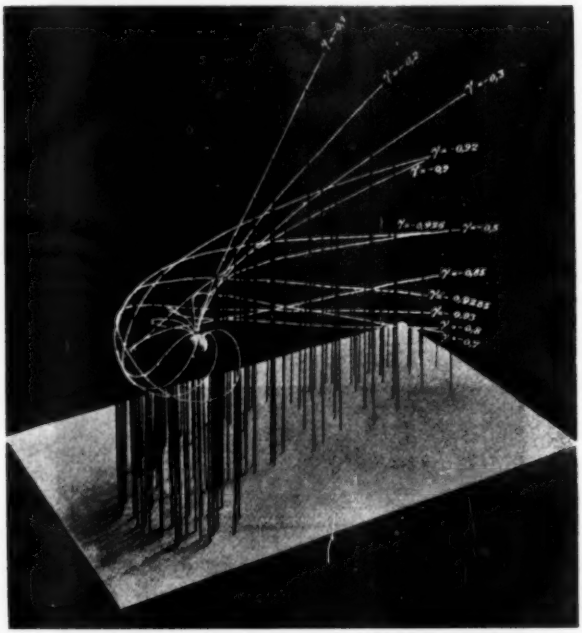

Fig. 20.—Electron paths around a magnetic dipole, after Störmer (Erg. kosm. Physik, vol. 1).

the aurorae can occur during the night. Störmer's computations have given paths which curve around the earth and reach it on the side opposite to the sun. Some such paths are shown in fig. 20. Other calculations by Störmer have shown how the rays can be deformed into bands and draperies and how in particular the remarkable horseshoe forms originate[78].

In this connection reference should be made to the echoes of short radio waves which are heard a number of seconds (from 3 to 25 sec.) after the original signal. Apparently they are not simply reflected repeatedly at one of the conducting layers and at the surface of the earth. Störmer[79] explains these echoes as reflections at the inner side of the toroidal space, which represents the boundary for the electronic orbits. The electromagnetic waves which have been emitted inside this toroidal space travel until they meet an obstacle in the form of the electrons outside the torus and are then reflected. The equatorial extension of the torus can be found by putting $\chi = 90°$ in eq. (29). The smallest value for r is then (for $\gamma_1 = 1$) $r = \sqrt{2} - 1$, or, with the value for $H\rho$ given on p. 410, $r \approx 310{,}000$ km., which would give an echo value of 2 sec. Considering that this is a minimum value, Störmer's hypothesis seems to account for these echoes quite satisfactorily.

While the corpuscular theory of the aurora explains a great number of observed facts, as has been shown there are certain fundamental difficulties which have not yet been overcome. A. Schuster has already pointed out that a corpuscular ring of great electrical charge, such as indicated by Störmer's theory, would dissipate very rapidly owing to the electrostatic repulsion between its different members. Similarly, doubts have been raised whether an electronic cloud emitted by the sun could reach the earth without dissipation by electrostatic repulsion, as was assumed in order to simplify the mathematical problem. This would perhaps be possible if the stream of corpuscles is very tenuous. However, such a stream would hardly be able to cause magnetic storms of a magnitude observed at the earth even if it could account for the auroral phenomena.

Chapman and Ferraro[80, 81] assumed that the sun emits at times a neutral stream of ions, electrons and perhaps neutral particles. This stream has a much lower velocity than assumed by Störmer, since only radio-active processes would give velocities of about one-third of the velocity of light. Milne[82] has shown how positive calcium ions can be driven away from the sun by radiation pressure with a relatively high velocity. Under equilibrium conditions the radiation pressure on the Ca^+ ions just balances the solar attrac-

tion. Collisions are very rare owing to the small density in the solar regions under consideration and may be neglected. If a Ca^+ ion happens to be accelerated outward it will absorb light of shorter wavelength. The shorter wavelengths are not depleted so much by absorption in the solar atmosphere and thus a gradual acceleration of the ion takes place up to a final velocity of 1,600 km/sec. The positive ions which are emitted by the sun in this way will be followed by negative charges. If such a process is to account for the emission of corpuscle streams from the sun additional assumptions will be necessary in order to explain why such a stream has sharp limits (local regions of higher temperatures on the sun which would frequently have to persist for months since magnetic storms re-occur often after one synodic rotation of the sun, i.e., 27 days). Such a stream would have to be very wide to sweep the earth for a period comparable to the duration of magnetic storms. A storm which persists for three days should extend over an angle of 40° seen from the sun. Chapman and Ferraro have studied the history of a neutral stream and found that within the stream the ions and electrons can move very nearly rectilinearly (apart from the thermal velocities which are assumed to be much smaller) and are only deflected very slightly by the field. As the stream approaches the earth its magnetic field tends to oppose further motion towards the more intense regions of the earth's magnetic field. Thus a hollow space around the earth is formed in the stream open at the night side of the earth. This hollow gradually shrinks as the surface advances. The density of the surface layer increases since the particles are only retarded when they enter the current layer. After a certain time the stream passes the earth owing to the relative motion of sun and earth, while a fraction of the particles which were near the earth remains for some time in the form of a ring around the equator. The constituents of this ring gradually disappear along the lines of magnetic force in the atmosphere in high latitudes.

This theory also is not satisfactory. Apart from the objections pointed out above, it is necessary to state that the effective range of Ca^+ ions as found by Milne is only .15 cm. at N.P.T., while the equivalent path in the earth's atmosphere down to 80 km., the lower limit of the aurora polaris, is at least 10 cm. even if the high tem-

perature above 40 km., which is indicated by the "skip" distance of the sound, is not taken into account.

Hulburt and Maris[82a] have given a different theory based on the assumption that the energy transport from the sun to the earth is not effected by corpuscles but by ultra-violet light. In general, the energy thus brought into the earth's atmosphere is not sufficient to cause magnetic storms and aurorae. But the authors assume that sometimes a small portion of the sun's surface, say 1/10,000, will reach a much higher temperature of the order of 30,000°. This would raise the energy radiated by the sun in the ultra-violet region from 500 to 1000A by a factor 10^5 while the total energy or solar constant would only increase by 1%. Now, some of the molecules in the upper atmosphere of the earth may suffer collisions of the second kind* with atoms excited by ultra-violet sunlight. Thus they can reach a velocity of about 10 km/sec. and a height of 40,000 km. If these originally neutral molecules are in their turn ionized they will spiral around the lines of magnetic force and approach the northern or southern polar zone. Chapman[82b] has pointed out that this ultra-violet theory is even less satisfactory than the corpuscular theory which we discussed in detail before. Particles of a velocity as low as 10 km/sec. can only penetrate down to about 200 km. into the atmosphere, while the observed lower limit of the aurora is at 80 to 90 km. The only mode of reconciliation would be to assume that aurorae are not directly caused by these returning corpuscles. But the definite shapes of the aurorae which can be accounted for by the theory of direct corpuscular emission from the sun contradict this assumption. Furthermore, Chapman shows that the theory of Hurlburt and Maris does not give the observed characteristics of magnetic storms.

It is seen that the corpuscular theory explains successfully quite a number of the phenomena observed in aurorae and magnetic storms. We may therefore assume that it is at least partly correct. The fundamental problem, however, how the particles come from the sun to the earth, is still unsolved.

*In a "collision of the second kind" an excited atom gives its excitation energy, in part or completely, to an originally neutral atom whose excitation potential is smaller. In case of partial energy transfer, the rest of the energy is transformed into kinetic energy.

METEOR NEWS

Observations relating to meteors and meteorites are cordially invited.

Observations of the Orionids in 1936

M. Eppe Loreta, some of whose observations of persistent trains were reported last month, is rapidly becoming one of the most outstanding and successful amateur astronomers in Europe. In addition to his meteor work, which gives good evidence of his skill as an observer, he is a regular contributor of variable star observations to the A.A.V.S.O. and has, within the last year, published a series of

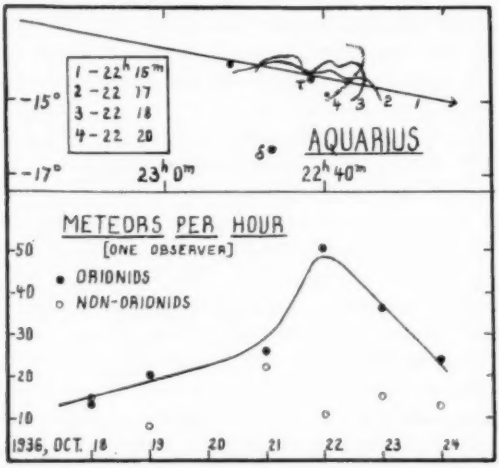

Figure 1

Above.—Train drift of a bright Orionid meteor which appeared at 22h 15m, G.C.T., Oct. 22, 1936.

Below.—Orionid rates observed at Bologna by M. Loreta, 0.30-2.30 M.E.T.

magnitude estimates for a number of asteroids and observations of solar and lunar eclipses and of the zodiacal light. He made an independent discovery of Nova Lacertae in June, 1936, and carries out observations of novae along with his variable star programme. Loreta's work is a splendid example of how an amateur with very little equipment or resources can add to our astronomical knowledge.

The writer has just received from M. Loreta a fine series of observations of the Orionid shower, which was carried out at Bologna. Observations were made on six out of seven nights commencing with Oct. 17-18, 1936. The numbers of Orionids and Non-Orionids observed for 25 minutes out of each half-hour between 9.30 p.m. and 2.30 a.m. M.E.T. were recorded. On each date a rate of 2 to 5 Orionids per hour was observed at the beginning of the night and this increased quite smoothly, becoming approximately constant for the last two hours of observation, 12.30 to 2.30. The mean rate for this period, found by averaging the hourly rate for 1.00, 1.30 and 2.00, is plotted in figure 1. These rates are for one observer and must be multiplied by the factor 3.5 to make them comparable to the rates for six observers usually published in these notes. It will be seen that the Orionid rate reaches a definite maximum on the night of Oct. 21-22 which, as M. Loreta points out, is later than expected. Unfortunately, he was unable to make any observations on Oct. 19-20 because of cloudy weather. Word was received from another Italian amateur that the Orionids were more numerous on Oct. 19-20 than the Perseids on their maximum night, but Loreta does not give the details of this observation so it is hard to judge of its reliability. Since Prentice has shown* that there are probably several Orionid radiants active simultaneously, it is possible that the Orionid shower has no definite maximum on one particular night but several maxima occurring on different nights.

On the average the Orionids have maximum rates only about one-third of the Perseid rates. The Orionid rate observed by Loreta on Oct. 21-22 compares favourably with the Perseid rates usually recorded on the maximum night, indicating that the Orionid shower was particularly rich in 1936. It is unfortunate that we have no Canadian observations of these meteors. Photographic observations had been planned at the Dunlap Observatory but on the only clear night when these could have been carried out the electric power was turned off in the district, thus making it impossible to operate the cameras.

Loreta observed 457 Orionid meteors and 294 others in the six nights of observation. The magnitude distribution and the duration of the persistent trains are given in the accompanying table.

*Prentice, Jour. B.A.A. vol. 46, p. 329, 1936.

The mean Orionid magnitude corresponds very closely to that for the Perseids reported last month. Approximately 50 per cent. of the Orionid meteors were accompanied by persistent trains one second or longer in duration. Very few of the other meteors had persistent trains.

MAGNITUDES

Mag.	−2	−1	0	1	2	3	4	5	Total	Mean Mag.
Orionids.....	1	1	4	30	113	148	132	28	457	2.94
Non-Orionids			1	5	46	110	109	23	294	3.33

PERSISTENT TRAINS

Duration	1s	2s	3s	4s	5s	6s	10s	15s	360s
Orionids.....	44	82	62	19	12	1	2	1	1
Non-Orionids.....	5	6	1	1					

The brightest Orionid, a meteor of magnitude −2, appeared at 22h 15m G.C.T., Oct. 22. The persistent train was observed for six minutes with the aid of binoculars of 1.75 inch aperture. Four positions of this train were drawn and are reproduced in figure 1. Assuming a height of 90 km. for this train the observed drift indicates a minimum velocity of 50 km/sec. It is interesting also to note the effects of turbulence in the upper atmosphere as evidenced by the rapid deformation in the shape of this train.

P. M. M.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Civil War and Scientific Research

Many persons all over the world are much disturbed by reports of what is happening in Spain. To one who has been in that famous and historic country, or who has friends there, the news of bombardment, of dropping of bombs, of burning of blocks and of fierce aerial combats over Madrid is especially painful.

The special reason for the above remarks was the receipt a few days ago of a splendid *Boletin* from the Observatory of the Ebro, which is located near Tortosa, about 100 miles southwest of Barcelona, Spain. It is entitled "Contribucion al Estudio Climatologico de la Comarca de Tortosa" and is by Luis Rodés, S.J., the director. This observatory has been in operation for 25 years, and the indefatigable and agreeable Father Rodés gives a detailed analysis of the meteorological phenomena during this quarter-century. Numerous tables are followed by graphical representations and a student of the weather will find them well arranged and easy to consult. It may be of interest to state that the lowest reading of the barometer was 728.4 mm. on March 5, 1917, the highest 777.5 in January 1925. The maximum temperature of 38.4 C. was reached in August 1919 and 1923, the minimum of –2.8 in January 1918. Accompanying the *Boletin* is an "Atlas of Clouds" which contains 43 plates of typical and remarkable cloud forms seen at Tortosa.

The present writer wishes to congratulate Father Rodés and his staff on their persistent and successful labours. We in Canada are accustomed to repose quietly in the assurance of constitutional stability under democratic government and would wish that similar peaceful circumstances may soon replace the present unhappy conditions in Spain.

Recollections of Simon Newcomb

Simon Newcomb was born in Wallace, Nova Scotia, on March 12, 1835, and on the hundredth anniversary of his birth a cairn was unveiled there to his memory. The ceremony was attended by the United States Minister to Canada as well as by distinguished repre-

sentatives of Canada. On May 28 of this year a bust of Newcomb was placed in the Hall of Fame in New York City. It would have given me much pleasure to have attended this function but I was unable to do so.

Newcomb died on July 11, 1909. In this JOURNAL three sketches of his life have been printed,—in the years 1909, 1913, 1935,—and Newcomb wrote his "Reminiscences". Many other obituary notices have also appeared. Thus considerable information about him is available. But we are always keen to hear personal recollections of a great man, and some very interesting ones of Newcomb are given by a person who was employed by him and who now occupies the chief position he filled. I refer to Dr. James Robertson, the Director of the Nautical Almanac Office, at the Naval Observatory, Washington; and the article which is entitled "Highlights on the Career of Simon Newcomb" was published in *Popular Astronomy* for November. I have taken the liberty of reprinting the concluding portion of it.

I well remember my first meeting with Professor Newcomb, over forty years ago. I had been offered a position in the Almanac Office, and had come to Washington to report for duty. The Office I found located in two places; all of the force, except Professor Newcomb, were at Nineteenth and Pennsylvania Avenue, while he was two blocks away, at Room 566 of the State, War and Navy Building. I was informed that he never definitely accepted anyone without a personal interview, and that he was too busy to see me then. I was told to call later that evening at his residence.

In the twilight of that evening, as I went up the broad stone steps of his home, my attention was arrested by the rapid approach of a cart and pony. It drew up to the curb, the driver stepped out, and literally anchored the cart and pony by dropping a large stone with a strap around it. Passing me on the steps, he opened the door and invited me in. I was struck immediately by the leonine appearance of the man. This word "leonine" I owe to James Bryce, when he was Ambassador of Great Britain to this country, who remarked to me in conversation that he once went to Oxford, a distance of ten miles, with no other purpose than just to take a look at Newcomb. He said that he was so "leonine"; also that he was the most striking personality he had ever met.

In the conversation with Professor Newcomb that night I was struck by the fact that I was asked not a question as to my education, experience as a computer, or really anything about my past experience at all. Years later, after becoming Director of the Nautical Almanac, I found from the files that

at that time he knew all about me, so the object of the interview was just to look me over.

After working at the Main Office about two months, I was told to report at his room in the Navy Building. I knew I was at the right place when I saw the cart and pony anchored outside. This cart and pony arrangement, and having a room removed from the others, were only devices to save time; and time was a great item to a man so overwhelmed with work as he was. I found a desk awaiting me. It faced his, but the high top of his desk, augmented by piles of books and manuscripts, cut off the view. There were revolving cases on both sides and at his back. From this point of vantage I saw for nearly two years how this remarkable man worked.

He was always hungry for results, and would not let anything deprive him of them. This disease must have been contagious, for everybody in the Office had it. Here was a corps, not of computers, but of mathematicians of ability, most of whom could have filled professorships in our leading universities with credit; all were striving to push the work along. When one was given a piece of work to do there were few, if any, instructions. One just went ahead and did it. This ability to surround himself with able assistants, and to keep up their interest in the work, was an asset of value, as it relieved him of many troublesome details, and reserved his intellect for the most difficult tasks.

Twice a week he lectured on mathematics at Johns Hopkins University. Those days he did not go to the dining room for lunch, but had John Hart, his messenger, bring it to his desk so that he could go direct to the train. One day Hart tripped on a rug, the lunch going in many directions; some of it on my arm, most of it around Newcomb's feet. Newcomb continued without missing a figure; his only remark being, "Hart, how could I live without you?"

I marvelled at his ability to carry on several pieces of work at the same time; of equal difficulty, but entirely different in nature. How he would concentrate on a piece of work with an intensity that made him oblivious to everything around him; then he would change to another without any confusion or loss of intensity! His brain seemed to be composed of several compartments, that automatically closed and opened as he passed from one subject to another. No energy was lost; all was used for results. It was this characteristic more than any other that made it possible for him to accomplish so much in one lifetime.

Optical Catalogues

In the October issue of the Journal reference was made to an interesting and valuable catalogue of spectroscopic instruments, and since then two more catalogues on optical apparatus have come to the writer's table. They also are from Bausch and Lomb, of

Rochester, N.Y. One deals with Lenses, Prisms, Mirrors; and the other with Motion Picture Projection Lenses and Condensers. Beautiful jewellery has a strong attraction for most people. Optical instruments have a similar appeal to the scientist, but besides having the charm of sparkling crystal and consummate workmanship they are of extreme value in our daily life.

The requirements of the moving picture industry have given rise to extraordinary demands on the glass maker as well as the optician. In some cases the glass must be very heat-resisting as well as transparent and of a suitable index of refraction. In the second catalogue is useful information regarding the correction of lenses, the best lens to use, and other matters. It is stated that in the newest type of condenser for a movie projector the rear lens has one spherical and one cylindrical surface, and the front lens has one spherical and one parabolic surface. In actual practice, it is said, this gives approximately fifty per cent. more light and greater uniformity on the screen than is attainable with any other condenser system. The light source recommended for the projection of standard film with these condensers is a 13.6 mm. high intensity arc at 125 amperes, —surely a powerful illuminant.

C. A. C.

MEETINGS OF THE SOCIETY

AT VANCOUVER

May 12, 1936.—The Annual Dinner and Members' night, making the 40th regular meeting, was held in the Union College dining room, University of B.C. About 20 members attended the dinner which was very much enjoyed. A splendid repast was furnished by Mr. and Mrs. Myers. Members adjourned after the dinner to the Science Building and the regular meeting held at 8.15 p.m., Mr. C. A. McDonald presiding.

The first speaker of the evening was the president, Mr. C. A. McDonald, who gave the members a very interesting outline of the methods used by mariners to plot their course across large bodies of water by the use of the "Great circles of sailing", obtaining by this method the shortest distance from point to point. Mr. McDonald explained that in the old days of sailing vessels and slow steamships most sailors were amateur astronomers also, but modern advancement, such as the use of radio and time signals, gyroscopic compasses, and other inventions had relieved the modern navigators of much of the labour involved in plotting courses across large bodies of water. The necessity of using the shortest distance between ports was always necessary, and the use of the great circles of the globe are as necessary to aviators to-day as they were to navigators in the past. Mr. McDonald gave a very clear and interesting address, which was very much enjoyed by the members.

The next speaker, Mr. H. P. Newton, intended to speak on the subject of "Lunar Occultations". Unfortunately, however, Mr. Newton explained that the Greenwich Nautical Almanac did not give the predictions for Canada, but only those for Greenwich, Edinburgh, and the Cape of Good Hope, including Johannesburg. The simple formulae for finding the approximate time of an occultation at another station is limited to short distances of a few hundred miles because the errors increase rapidly with increasing distance.

In the British Astronomical Association Handbook, occultations for Wellington and Dunedin are given. However, as stated in Vol. 30, No. 3, page 108, of our own JOURNAL, the Greenwich Nautical Almanac for 1937 will give the occultations visible at Montreal and Toronto and beginning with 1939, Vancouver and Calgary will be included.

Mr. Newton after this explanation gave a short talk on the planet Saturn. After stating the dimensions of the ball, rings and satellites, he drew attention to the phenomena of the disappearance of the rings, occultations, transits and eclipses of the satellites in 1936 and 1937. As these phenomena occur at approximately 15-year intervals the older members may not have another chance to observe them, and Mr. Newton expressed the opinion that he himself never expected to see them again.

Owing to smaller size and to greater distance Saturn needs a larger telescope to observe with efficiency than is needed with Jupiter, yet enough may be visible with even a 3-inch telescope to make the time spent well worth while.

Outdoor Meetings, Summer of 1936.—The first garden meeting was held on Saturday, July 18, at the residence of Mr. J. Teasdale, 4618 West 12th Avenue, where Mr. Teasdale's 6-inch Newtonian reflector was examined and used by the fifteen people attending the meeting.

The sky was very clear and visibility and seeing conditions good. Observations were made of the planet Jupiter, three of the satellites were observed in a transit, occulation and the shadow, respectively, during the evening.

The Nova in Lacerta was also observed, but as this star was decreasing rapidly in magnitude at this date it was not very interesting. Several constellations and star clusters were also looked at through the telescope.

The second garden meeting was held on Saturday, August 8, at the residence of Mr. H. P. Newton, 2619 Telford Avenue, Burnaby. Six members attended. Mr. Newton's 5¼-inch Grubb equatorial refractor was used, and the following objects observed: Jupiter and its spectrum, the globular cluster in Hercules, the Nova in Lacerta, Saturn and several other stars. The sky was partly clouded in the early part of the evening with fair seeing, which improved with clearing sky by 10 o'clock.

The third meeting was scheduled to be held at the residence of Mr. Jorgensen at 3454 East 27th Avenue, but owing to heavy rainfall during the day no meeting was held.

J. W. Moore, *Secretary.*

AT VICTORIA

May 12, 1936.—The final meeting of the session was held in the lecture hall of the Y.W.C.A. Commander H. R. Tingley was in the chair.

The lecture of the evening was presented by the secretary, Mr. Gordon Shaw.

The lecture, which was in popular vein, first pointed out that the planets will always hold prime interest to the beginner in astronomy, they being blood relations of our earth, members of the same family. Saturn, while not the largest member, was the most distinguished by reason of his unique system of rings. Saturn's distance from the sun, its size and its extreme oblateness were pointed out. The planet's mass and volume were compared with the other planets and with the earth. The surface markings were described and its period of rotation given. The nine satellites were named and described, the peculiar retrograde motion of Phoebe being noted. The history of the discovery of the rings by Galileo was given, their comparative size and phases being demonstrated by an excellent model of the planet made by Mr. H. Boyd Brydon. The model, being made on the scale of 1 inch to 10,000 miles, was suitably mounted to demonstrate the planet's inclination to the ecliptic. The material composing the rings was shown to be disintegral. The cause of the rings was unknown but several likely theories were presented. The speaker, while pointing out our insignificant size, nevertheless reminded his audience that perhaps greater in importance to the physical proportions of the Universe was the power of the human mind to push back the curtain of ignorance and superstition, revealing in their place exact knowledge and scientific fact.

Gordon Shaw, *Secretary.*

INDEX TO VOLUME XXX, 1936

A

Age of the Universe, The, *W. E. Harper*, 282.
Amateur Telescope Making, ed. by A. G. Ingalls, (Review) *C.A.C.*, 22.
American Astronomical Society—Cambridge Meeting, *C. A. Chant*, 331.
Animals, Sunspots and Abundance of, *D. A. MacLulich*, 233.
Annual General Meeting of the Royal Astronomical Society of Canada, 84.
Application of the Spectroscope to Astronomy, *R. K. Young*, 1, *F. S. Hogg*, 35.
Applied Spectroscopy, *H. J. C. Ireton*, 310.
Architecture of a Star, The, *R. M. Petrie*, 127.
Astronomer Looks for Life in the Heavens, *R. M. Petrie*, 131.
Astronomical Society of the Pacific, The Recent Annual Meeting of the, *A. McKellar*, 305.
Atmosphere of the Earth, The, *W. E. Harper*, 51.
Atmosphere, The Physical State of the Upper, *B. Haurwitz*, 315, 349, 397.
Aurora, The (in Physical State of the Upper Atmosphere), 315, 349, 397
Aurora, The Green Line of the, *J. F. Heard*, 55.
Auroral Display, A Ribbon-like, 343.

B

Bartky Walter, Highlights of Astronomy, (Review), *W. H. Gage*, 247.
Bausch and Lomb, Catalogues, 421.
Beobachtung Veränderlicher Sterne, Die, by R. Müller, (Review), *F.S.H.*, 22.
Beyond the Stratosphere, *W. G. Hale*, 175, 253.
Brydon, H. Boyd, Telescope Mountings for Amateur Builders, 377.

C

Call to Amateurs, A, *D. W. Rosebrugh*, 285.
Carolina Bays and their Supposed Meteoric Origin, 57.
Chant, C. A., American Astronomical Society—Cambridge Meeting, 331 (also see Notes and Queries and Reviews).
Civil War and Scientific Research, 419.
Collier, H. B., A Lunar Halo in Alberta, 165.
Constellations, J. Stokley and others (Review), *C.A.C.*, 337.
Cooper, G. H., The Druid Bible, (Review), *C.A.C.*, 367.
Cosmic Radiations and Astronomical Research, *Lachlan Gilchrist*, 65.
Crust of the Earth, The, *W. E. Harper*, 136.
Cycles of Reduced Ideals in Quadratic Fields, E. L. Ince, (Review), *Richard Brauer*, 106.

D

De Kinder, F. J., Solar Halo Observed at Montreal, July 6, 1936, 292.
Dimensions and Structure of the Galactic System, The, *J. S. Plaskett*, 153.
Dominion Astrophysical Observatory, Notes from, *W. E. Harper*, 296.
———, Promotions at, 199.
Druid Bible, The, G. H. Cooper, (Review), *C.A.C.*, 367.

Durrant, J. E., A New Geometry, Analytic-Synthetic, (with H. R. Kingston), (Review), *C.A.C.*, 368.

E

Earth, Atmosphere of the, *W. E. Harper*, 51.
———, The Crust of the, *W. E. Harper*, 136.
Earthquake of November 1, 1935, The Temiskaming, *E. A. Hodgson*, 113.
Eastern Standard Time (Rhyme), *"Gentleman Jim"*, 168.
Eclipse of June 19, 1936, The Total, 14.
Eclipses, *A. W. Grant*, 187.
Evolution of the Solar System (B.A. discussion), 392.
Extra-galactic Nebulae, New Velocities of, 31.

F

Factor Table (B.A. Mathematical Tables, Vol. V), J. Peters and others, (Review), *J.F.H.*, 248.
Fath, E. A., Through the Telescope, (Review), *C.A.C.*, 191.
Fireball, 101, 141.
Frequency Distribution of the Time Intervals Between Meteors, 338.
Frost, E. B., Let's Look at the Stars, (Review), *W.E.H.*, 143.

G

Gage, O. A., The 200-inch Telescope Eye, 169.
Galactic System, The Dimensions and Structure of the, *J. S. Plaskett*, 153.
Gilchrist, Lachlan, Cosmic Radiations and Astronomical Research, 65.
Grant, A. W., Eclipses, 187.
Gray, Robert Alexander, (Obituary), 33, 62.
Green Flash, 299.
Green Line of the Aurora, The, *J. F. Heard*, 55.

H

Hale, W. G., Beyond the Stratosphere, 175.
Harper, W. E., Note on Nova Herculis, 124; Stellar Spectroscopy, 273; Notes from the Dominion Astrophysical Observatory, 296; Radio Talks, 15, 49, 136, 282. (also see Reviews).
Haurwitz, B., The Physical State of the Upper Atmosphere, 315, 349, 397.
Heard, J. F., Green Line of the Aurora, 55 (also see Reviews).
Highlights of Astronomy, W. Bartky, (Review), *W. H. Gage*, 247.
Hodgson, E. A., The Timiskaming Earthquake of November 1, 1935, 113.
Hogg, E. G., The Names of Astronomical Objects, 333.
Hogg, F. S., Application of the Spectroscope to Astronomy, 35. (also see Reviews).
Horning, J. H., Robert Alexander Gray, 33.

I

Ince, E. L., C cles of Reduced Ideals in Quadratic Fields, (Review), *Richard Brauer*, 106.
Ingalls, A. G. ed., Amateur Telescope Making, 4th ed., (Review), *C.A.C.*, 22.
Ireton, H. J. C., Applied Spectroscopy, 310.

J

Japanese Observations of the Leonids, 250.
Jones, H. Spencer, Worlds Without End, (Review), *C.A.C.*, 23, 106.

K

Kingston, H. R., A New Geometry, Analytic—Synthetic (with J. E. Durrant), (Review), *C.A.C.*, 368.
Kuiper, G. P., White Dwarf, A. C.+ 70°8247, 48.

L

Lallemand, A., The Present State of our Knowledge of the Solar Corona, 287.

Lectures before the Society: EDMONTON CENTRE—The Construction of a Home-made Telescope, *C. C. Wates*, 109; The Motions of the Earth, *J. W. Campbell*, 109; Weighing the Earth, *E. S. Keeping*, 109; The Tides, *W. O. Coulman*, 109; What is a Star? *C. S. Beals*, 109; The Structure of the Earth, *R. L. Rutherford*, 109; The Earth's Atmosphere, *L. H. Nichols*, 109; Galileo, *W. H. Poole*, 110; The Evolution of the Solar System, *A. J. Cook*, 201; What are the Things of Value that a Centre can offer its lay Members? *J. W. Campbell*, 201. MONTREAL CENTRE—Telescope Making, *A. Donnelly*, 302; Sun-spots, *R. De Lury*, 302; What a Star Really is, *E. R. Peterson*, 303; Constellations, *H. F. Hall*, 303; The Astronomical Knowledge of the Mayas, *W. D. Lighthall*, 303; Man and His Universe in Chaucer's Time, *R. A. Hamilton*, 303; Cosmological Problems of Physics, *A. Haas*, 304; Some Fundamental Ideas of Physics, *A. Haas*, 304. OTTAWA CENTRE—Interstellar Matter, *P. M. Millman*, 207. TORONTO CENTRE—Meeting of the International Astronomical Union in Paris, *C. A. Chant*, 148; Motion Picture Colour Photography, *G. R. Anderson*, 149; Eclipsing Binaries, *J. F. Heard*, 150; Applied Spectroscopy, *H. J. C. Ireton*, 203; The Structure of Atomic Nuclei, *Elizabeth Allin*, 204; Parallax of a Star, *H. G. Duncalfe*, 256; The Age of the Earth, *J. Satterly*, 256; Concepts of Velocity, Acceleration, Energy and Potential, *S. Beatty*, 257; Seasonal Changes in the Heavens, *J. H. Horning*, 257; Naval Observatory at Washington, *C. A. Chant*, 258; A Trip to the Moon, Eclipse of the Sun, (films) shown by *R. H. Combs*, 376. VANCOUVER CENTRE—The Moon, *Laura Anderson*, 63; The Planets and Asteroids, *Seto More*, 63; The Sun, *J. W. Moore*, 63; Laboratory Methods in Bacteriology, *D. C. B. Duff*, 151; The Astronomy of the Poets, *W. E. Harper*, 205; Colour, *J. C. Davidson*, 258; The Making of a Refracting Telescope, *J. C. Jorgensen*, 259; Methods in Finishing a Parabolic Mirror, *J. Teasdale*, 260; Auroral Displays, *E. C. Thrupp*, 260; Great Circles of Sailing, *C. A. McDonald*, 423; Saturn, *H. P. Newton*, 423. VICTORIA CENTRE—The Spectroscope and its Uses, *A. McKellar*, 64; Some Sidelights of Astronomy in Europe, *J. S. Plaskett*, 261; Curiosities in Numbers, *James Duff*, 262; Recent Developments in the Making of Large Telescopes (symposium), 262; The Solar Cycle and some Terrestrial Effects, *W. E. Harper*, 263; Effects of the Sun-spot Cycle on Radio Reception (symposium), 264; The Planets, *Gordon Shaw*, 424. WINNIPEG CENTRE—A Theory of the Universe, *H. P. McPhail*, 205.

Leonids, 1935, 25.

——— during Recent Years, The Relative Numbers of, 27.

———, Japanese Observations of the, 250.

Let's Look at the Stars, E. B. Frost (Review), *W.E.H.*, 143.

List of Fellows and Members, i.

Loretta, Eppe, Observations of the Orionids in 1936, 416.

Lunar Halo in Alberta, A., *H. B. Collier*, 165.

Lyrids at Bologna, Italy, Observations of the, 249.

M

MacLulich, D. A., Sunspots and Abundance of Animals, 233.
McKellar, A., The Recent Annual Meeting of the Astronomical Society of the Pacific, 305.
Meteor News, 25, 57, 101, 139, 192, 249, 293, 338, 369, 416.
Meteor Photographs taken with a Rotating Shutter, 101.
Meteor Photography, 60, 192.
Meteor Radiant Photographically Determined, A., 293.
Meteor Rates, The Effect of Observing Conditions on, 104.
Meteor Spectra—List III, 249.
Meteorites, Mining for, W. E. Harper, 15.
Meteors: Leonids, 25, 27, 250, Lyrids, 249, Orionids, 416, Perseids, 293.
Meteors, Nebulous, 60, 139.
Middleton, W. E. K., Temperature Profiles in Toronto (with F. G. Millar), 265.
Miller, D. C., Science and Philosophy, 345.
Millar, F. G., Temperature Profiles in Toronto (with W. E. K. Middleton), 265.
Millman, P. M. (See Meteor News.)
Mining for Meteorites, *W. E. Harper*, 15.
Mitchell, S. A. and others, Observations of Long Period Variables and Magnitudes and Coordinates of Comparison Stars, (Review), *H.B.S.H.*, 105.
Müller, R., Die Beobachtung Veränderlicher Sterne, (Review), *F.S.H.*, 22.

N

Names of Astronomical Objects, The, *E. G. Hogg*, 333.
Nebulae, New Velocities of Extra-galactic, 31.
New Geometry, Analytic—Synthetic, A, J. E. Durrant and H. R. Kingston, (Review), *C.A.C.*, 368.
Newcomb, Simon, Recollections of, 419.
Notes and Queries, 31, 61, 108, 145, 197, 253, 299, 343, 372, 419.
Nova Herculis, Note on, *W. E. Harper*, 124.
Nova Lacertae, *R. K. Young*, 209.

O

Obituary: Gray, Robert Alexander, 33, 62.
Observatory, A Summer Community, 300.
Observatory of San Miguel, The, 344.
Observations of Long Period Variables and Magnitudes and Coordinates of Comparison Stars, by S. A. Mitchell and others, (Review), *H.B.S.H.*, 105.
Occultations for Amateurs, 108.
Optical Catalogues, 421.
Orionids in 1936, 416.

P

Perseid Meteors in 1936, 293.
Persistent Trains made In Italy, Observations of, 369.
Peters, J. and others, Factor Table: (B.A. Mathematical Tables, Vol. V), (Review), *J.F.H.*, 248.
Petrie, R. M., The Architecture of a Star, 127; The Astronomer Looks for Life in the Heavens, 131.
Physical State of the Upper Atmosphere, The, *B. Haurwitz*, 315, 349, 397.
Planetary Atmospheres, *W. E. Harper*, 49.
Planets, Surface Temperature of the, *W. E. Harper*, 18.

Plaskett, J. S., The Dimensions and Structure of the Galactic System, 153.

Present State of our Knowledge of the Solar Corona, The, *A. Lallemand*, 287.

R

R.A.S.C. Annual General Meeting, 84.

Radio Talks, *W. E. Harper:* Mining for Meteorites, 15; Surface Temperatures of the Planets, 18; Planetary Atmospheres, 49; The Atmosphere of the Earth, 51; The Crust of the Earth, 136; The Age of the Universe, 282.

Reviews of Publications: Die Beobachtung Veränderlicher Sterne, by R. Müller, *F.S.H.*, 22; Amateur Telescope Making, ed. by A. G. Ingalls, *C.A.C.*, 22; Worlds Without End, by H. S. Jones, *C.A.C.*, 23, 106; Observations of Long Period Variables and Magnitudes and Co-ordinates of Comparison Stars, by S. A. Mitchell and others, *H.B.S.H.*, 105; Cycles of Reduced Ideals in Quadratic Fields, by E. L. Ince, *Richard Brauer*, 106; Stars and Telescopes, by James Stokley, *C.A.C.*, 143; Let's Look at the Stars, by E. B. Frost, *W.E.H.*, 143; Through the Telescope, by E. A. Fath, *C.A.C.*, 191; Highlights of Astronomy, by Walter Bartky, *Walter H. Gage*, 247; Factor Table (B.A. Mathematical Tables, Vol. V), by Peters and others, *J.F.H.*, 248; Constellations, by Stokley and others, *C.A.C.*, 337; The Druid Bible, by George H. Cooper, *C.A.C.*, 367; A New Geometry, Analytic—Synthetic, by Durrant and Kingston, *C.A.C.*, 368.

Robertson, James, Recollections of Simon Newcomb, 420.

Rosebrugh, D. W., A Call to Amateurs, 285.

S

San Miguel, The Observatory of, 344.

Science and Philosophy, *D. C. Miller*, 345.

Solar Corona, The Present State of our Knowledge of the, *A. Lallemand*, 287.

Solar Eruptions and Terrestrial Phenomena, 255.

Solar Halo Observed at Montreal, July 6, 1936, *F. J. De Kinder*, 292.

Solar System, Evolution of (B.A. discussion), 392.

Spectroscope to Astronomy, The Application of, *R. K. Young*, 1; *F. S. Hogg*, 35.

Spectroscopic Binary H.D. 34762, The, *W. H. Stilwell*, 212.

Spectroscopy, Applied, *H. J. C. Ireton*, 310.

Spectroscopy, Stellar, *W. E. Harper*, 273.

Stars and Telescopes, by James Stokley, (Review), *C.A.C.*, 143.

Stellar Spectroscopy, *W. E. Harper*, 273.

Stilwell, W. H., The Spectroscopic Binary H.D. 34762, 212.

Stokley, James, Stars and Telescopes, (Review), *C.A.C.*, 143.

Stokley, J. and others, Constellations, (Review), *C.A.C.*, 337.

Störmer, C. (see Aurora).

Stratosphere, Beyond the, *W. G. Hale*, 175, 253.

Sunspots and Abundance of Animals, *D. A. MacLulich*, 233.

Sunspots and Weather Forecasting in Canada, *A. Thomson*, 215.

Surface Temperature of the Planets, *W. E. Harper*, 18.

T

Telescope Mountings for Amateur Builders, *H. Boyd Brydon*, 377.
Telescope—200-inch, *O. A. Gage*, 169.
———, Progress on the, *C.A.C.*, 375.
Temperature Profiles in Toronto, *W. E. K. Middleton and F. G. Millar*, 265.
Temperature of the Planets, Surface, *W. E. Harper*, 18.
Thomson, Andrew, Sunspots and Weather Forecasting in Canada, 215.
Through the Telescope, E. A. Fath, (Review), *C.A.C.*, 191.
Timiskaming Earthquake of November 1, 1935, The, *E. A. Hodgson*, 113.
Total Eclipse of June 19, 1936, The, 14.

U

Upper Atmosphere, The Physical State of the, *B. Haurwitz*, 315, 349, 397.

W

Weather Forecasting in Canada, Sunspots and, *A. Thomson*, 215.
White Dwarf A.C.+70°8247, *G. P. Kuiper*, 48.
Worlds Without End, by H. Spencer Jones, (Review), *C.A.C.*, 23, 106.

Y

Young, R. K., The Application of the Spectroscope to Astronomy, 1; Nova Lacertae, 209.

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CONTENTS FOR VOLUME XXX, 1936

I. JANUARY

The Application of the Spectroscope to Astronomy (with Plate I-IV) *R. K. Young* 1

The Total Eclipse of June 19, 1936 14

Radio Talks over CFCT, Victoria, B.C.—77. Mining for Meteorites; 78. Surface Temperatures of the Planets ..... *W. E. Harper* 15

Review of Publications (*Die Beobachtung Veränderlicher Sterne*, by R. Müller; *F.S.H. Amateur Telescope Making*, ed. A. G. Ingalls; *C.A.C. Worlds Without End*, by H. S. Jones; *C.A.C.*) 22

Meteor News (Photographic Observations of the Leonids, 1935 (with Plate V); Visual Observations of the Leonids, 1935; The Relative Numbers of Leonids during Recent Years) ..... *P.M.M.* 25

Notes and Queries (New Velocities of Extra-galactic Nebulae; Smoking in Boston a Hundred Years Ago; Rejects Daylight-saving Time) .. *C.A.C.* 31

II. FEBRUARY

Robert Alexander Gray, 1861-1935 (with Plate VI) ..... *J. H. Horning* 33

The Application of the Spectroscope to Astronomy ..... *Frank S. Hogg* 35

The White Dwarf A.C.+70°8247, the Smallest Star Known ... *G. P. Kuiper* 48

Radio Talks over CFCT, Victoria, B.C.—79. Planetary Atmospheres; 80. The Atmosphere of the Earth ..... *W. E. Harper* 49

The Green Lines of the Aurora ..... *J. F. Heard* 55

Meteor News (The Carolina Bays and their Supposed Meteoric Origin; Meteor Photography in Texas; Nebulous Meteors) ..... *P.M.M.* 57

Notes and Queries (Prophets of Science; Royalty and the Time; The Late R. A. Gray) ..... *C.A.C.* 61

Meetings of the Society—Vancouver, Victoria 63

III. MARCH

Cosmic Radiations and Astronomical Research ..... *Lachlan Gilchrist* 65

Annual General Meeting of the Royal Astronomical Society of Canada: Reports of the Recorder, Curator, Assistant Librarian, Assistant Secretary and Secretaries of the Centres 84

Annual General Meetings: Reports of the General Treasurer and Treasurers of the Centres 96

Meteor News (A Brilliant Fireball; Meteor Photographs taken with a Rotating Shutter; Effect of Observing Conditions on Meteor Rates) *P.M.M.* 101

Review of Publications (*Observations of Long Period Variables and Magnitudes and Co-ordinates of Comparison Stars*, by S. A. Mitchell and others; *H.B.S.H. Worlds Without End*, by H. S. Jones. *Cycles of Reduced Ideals in Quadratic Fields*, by E. L. Ince; *Richard Brauer*..... 105
Notes and Queries (Occulations for Amateurs).....*C.A.C.* 108
Meetings of the Society—Edmonton, Vancouver, Victoria. Officers elected at other Centres..... 109

IV. APRIL

The Temiskaming Earthquake of November 1, 1935. The Location of the Epicentre and Determination of Focal Depth (with Plates VII-XIII) *Ernest A. Hodgson* 113
Note on Nova Herculis.....*W. E. Harper* 124
The Architecture of a Star.....*R. M. Petrie* 127
The Astronomer Looks for Life in the Heavens.....*R. M. Petrie* 131
Radio Talks over CFCT, Victoria, B.C.—81. The Crust of the Earth *W. E. Harper* 136
Meteor News (Nebulous Meteors; Two Bright Fireballs).....*P.M.M.* 139
Review of Publications (*Stars and Telescopes*, by James Stokley; *C.A.C. Let's Look at the Stars*, by E. B. Frost; *W.E.H.*)..... 143
Notes and Queries (Not a Foreign Country; Error in the 1936 *Handbook*) *C.A.C.* 145
Meetings of the Society—Toronto, Vancouver..... 148

V. MAY-JUNE

The Dimensions and Structure of the Galactic System (with Plate XIV) *J. S. Plaskett* 153
A Lunar Halo in Alberta.....*H. B. Collier* 165
Eastern Standard Time (A Rhyme).....*"Gentleman Jim"* 168
The 200-inch Telescope Eye (with Plates XV-XXI).....*O. A. Gage* 169
Beyond the Stratosphere: Can Man Travel to the Stars?.....*W. G. Hale* 175
Eclipses.....*A. W. Grant* 187
Review of Publications (*Through the Telescope*, by E. A. Fath; *C.A.C.*)..... 191
Meteor News (Summer Meteor Observations; Recent Programmes of Meteor Photography; The Expectation of Success in Meteor Photography).....*P.M.M.* 192
Notes and Queries (Further Notes on Florida; Northward from Lat. 27° 40′ to Lat. 43° 40′; Promotions at the Dominion Astrophysical Observatory; Supposed Error in 1936 *Handbook*; Error in Dr. Hodgson's Article) *C.A.C.* 197
Meetings of the Society—Edmonton, Toronto, Vancouver, Winnipeg, Ottawa..... 201

VI. JULY-AUGUST

Nova Lacertae (with Plate XXII) ..... *R. K. Young* 209
The Spectroscopic Binary H.D. 34762 ..... *Walter H. Stilwell* 212
Sunspots and Weather Forecasting in Canada ..... *Andrew Thomson* 215
Sunspots and Abundance of Animals ..... *D. A. MacLulich* 233
Review of Publications (*Highlights of Astronomy*, by Walter Bartky; *Walter H. Gage. Factor Table, B.A. Mathematical Tables, Vol. V*, by Peters and others; *J.F.H.* 247
Meteor News (Meteor Spectra—List III; Observations of the Lyrids at Bologna, Italy; Japanese Observations of the Leonids) ..... *P.M.M.* 249
Notes and Queries (Beyond the Stratosphere; Cash Prize for a Manuscript on a Science Subject; Solar Eruptions and Terrestrial Phenomena) *C.A.C.* 253
Meetings of the Society—Toronto, Vancouver, Victoria 256

VII SEPTEMBER

Temperature Profiles in Toronto .... *W. E. K. Middleton and F. G. Millar* 265
Stellar Spectroscopy ..... *W. E. Harper* 273
Radio Talks over CFCT, Victoria, B.C.—82. The Age of the Universe *W. E. Harper* 282
A Call to Amateurs ..... *D. W. Rosebrugh* 285
The Present State of our Knowledge of the Corona ..... *A. Lallemand* 287
Solar Halo Observed at Montreal, July 6, 1936 ..... *F. J. De Kinder* 292
Meteor News (Note on the Perseid Meteors in 1936; A Meteor Radiant Photographically Determined) ..... *P.M.M.* 293
Notes from the Dominion Astrophysical Observatory ..... *W.E.H.* 296
Notes and Queries (Izaak Walton Says; The Green Flash; Prediction of an Earthquake; A Summer Community Observatory; University Men as Colonizers) ..... *C.A.C.* 299
Meetings of the Society—Montreal 302

VIII. OCTOBER

The Recent Annual Meeting of the Astronomical Society of the Pacific (with Plates XXIII, XXIV) ..... *Andrew McKellar* 305
Applied Spectroscopy ..... *H. J. C. Ireton* 310
The Physical State of the Upper Atmosphere ..... *B. Haurwitz* 315
American Astronomical Society—Cambridge Meeting ..... *C. A. Chant* 331
The Names of Astronomical Objects ..... *E. G. Hogg* 333
Review of Publications (*Constellations*, by Stokley and others) .... *C.A.C.* 337
Meteor News (The Frequency Distribution of the Time Intervals between Meteors) ..... *P.M.M.* 338
Notes and Queries (A Ribbon-like Auroral Display; The Observatory of San Miguel; A Very Useful Catalogue) ..... *C.A.C.* 343

IX. NOVEMBER

Science and Philosophy ..... *Dayton C. Miller* 345
The Physical State of the Upper Atmosphere (*Continued*) .... *B. Haurwitz* 349
Review of Publications (*The Druid Bible*, by George H. Cooper; *C.A.C.* *A New Geometry, Analytic—Synthetic*, by Durrant and Kingston; *C.A.C.*) 367
Meteor News (Observations of Persistent Trains made in Italy) .... *P.M.M.* 369
Notes and Queries (Bust of Lord Kelvin for the Smithsonian Institution; Fahrenheit and his Thermometer Scale; Two High-altitude Records; Progress on the 200-inch Telescope) ..... *C.A.C.* 372
Meetings of the Society—Toronto 376

Appendix to Vol. XXX—List of Members of the Society ..... i to xxiv

X. DECEMBER

Telescope Mountings for Amateur Builders (with Plates XXV, XXVI) *H. Boyd Brydon* 377
Evolution of the Solar System ..... From *Nature* 392
The Physical State of the Upper Atmosphere (*Continued*) ..... *B. Haurwitz* 397
Meteor News (Observation of the Orionids in 1936) ..... *P.M.M.* 416
Notes and Queries (Civil War and Scientific Research; Recollections of Simon Newcomb; Optical Catalogues) ..... *C.A.C.* 419
Meetings of the Society—Vancouver, Victoria 423
Index to Volume XXX 425
Table of Contents ..... iii-vi

The Royal Astronomical Society of Canada

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